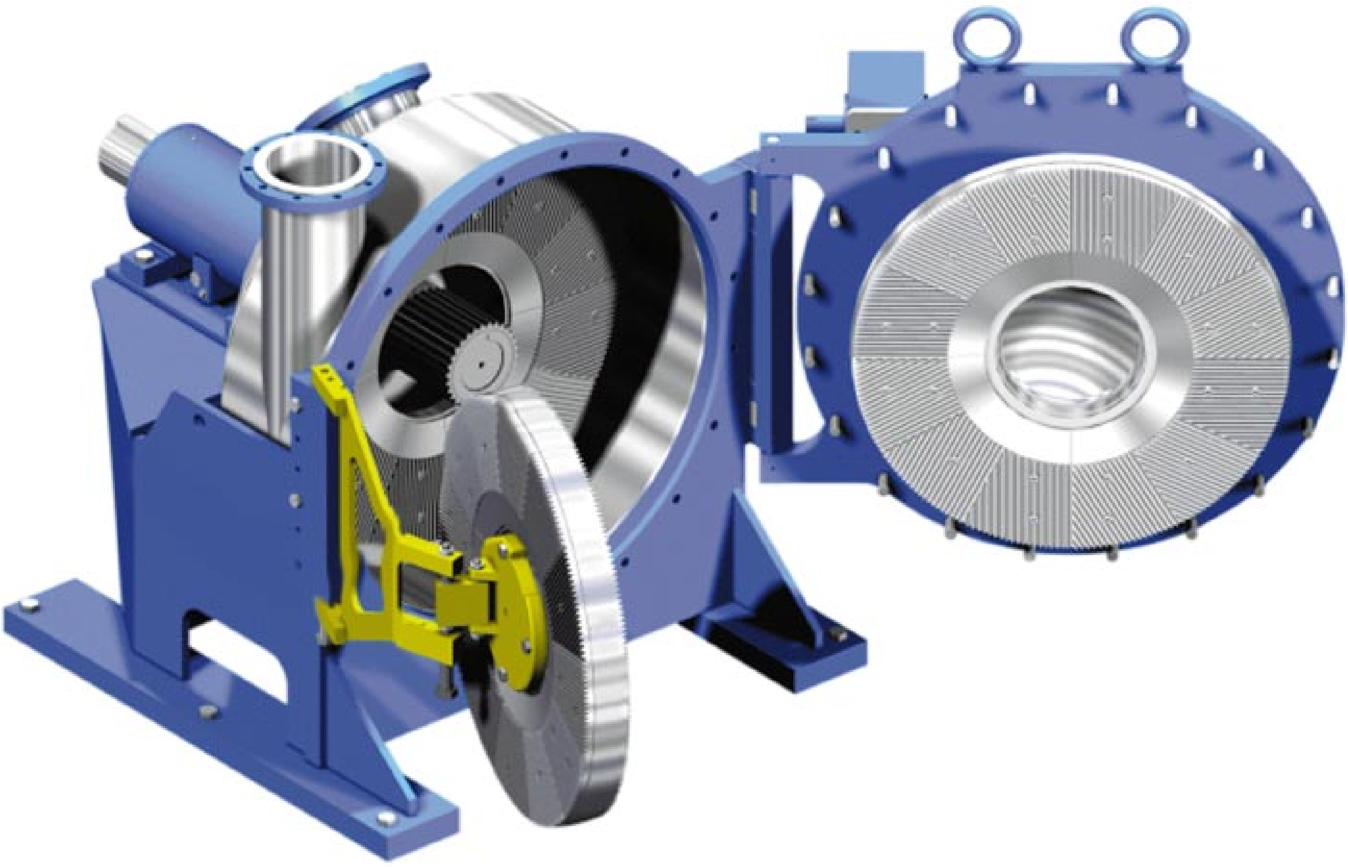
GOOD PRACTICE GUIDE 114

Energy efficient practices and technologies for the refining of papermaking stock



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GOOD PRACTICE GUIDE 114

ENERGY EFFICIENT PRACTICES AND TECHNOLOGIES FOR THE REFINING OF PAPERMAKING STOCK

This Guide is No. 114 in the Good Practice Guide series and is intended for use by experienced personnel. It brings attention not just to state of the art equipment, but also the potential for low-cost system modification to existing equipment and layout. The practices described in this Guide are for refining virgin chemical fibre and, in some cases, recycled fibre. The Guide is intended for practical use and case studies are provided wherever possible to illustrate a particular practice.

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LIST OF RELEVANT PUBLICATIONS

GIL53. OPTIMISING ENERGY USE IN PULPERS AND REFINERS
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GPG83. ENERGY EFFICIENT LIQUID RING VACUUM PUMP INSTALLATIONS IN THE PAPER INDUSTRY
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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

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1. INTRODUCTION

New fibre refiners on the market offer potential energy savings when replacing older types of refiners, albeit at a premium in capital investment. However there are many ways in which energy savings can be made by means of good practice, e.g. maintenance, correct capacity and filling design. Existing refiners are often operated at levels well below their optimum efficiency and are not always well maintained.

The purpose of this Good Practice Guide is not just to bring attention to state of the art equipment, but to illustrate the potential for low cost system modification to existing equipment and layout.

The practices described in this Guide are for refining virgin chemical fibre and, in some cases, recycled fibre. Energy use in the production of mechanical papers is a topic in its own right. The amount of refining used to manufacture a given product will vary according to the properties required, but is almost always energy intensive. The potential energy savings are great – drying is the only process in papermaking that uses more energy.

For the majority of papers and boards, the papermaking processes use similar technologies to manufacture the final product. However, the raw materials used and method of operation can vary widely. Fig 1 illustrates a typical breakdown of energy use.

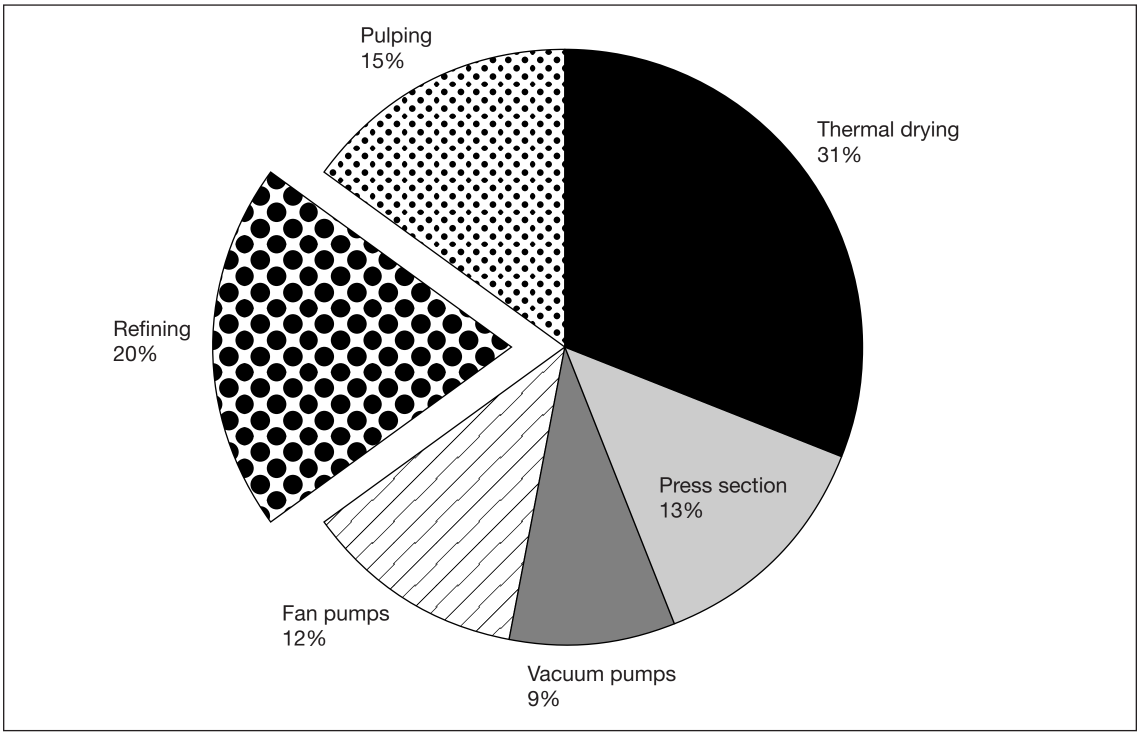

Fig 1 Typical energy use in papermaking processes

The UK Paper Industry is concentrated on 87 sites and produces a wide range of papers and board from 97 mills. These mills produce in the region of 6.5 million tonnes of product each year. For those grades requiring significant amounts of energy for the refining of chemical pulps (approximately 3.5 million tonnes of the annual product), the average gross electrical energy used in refining is 200 kWh/tonne (depending on refiner condition). Therefore, refining this pulp requires 700 MWh of electrical energy at a cost of around £20 million/year. While only an approximation, this figure gives an idea of the potential savings to be made industry-wide. The case histories presented in this Guide indicate that energy savings of 20 - 25% are possible. For a medium-sized fine paper mill refining 30,000 tonnes/year this could represent savings of £45,000.

This Guide is intended for practical use and wherever possible case studies are provided to illustrate a particular practice. It should be noted that there is no intent to comment adversely on specific manufacturers; the operating problems encountered in the case studies were due to refiner wear or incorrect sizing, not because of the name on a casing.

The Guide is divided into six further Sections.

Section 2 provides a background to refining and considers the primary effects, quantification and application of refining. Refining and stock parameters (as related to energy) are discussed and the relation of refining to other papermaking processes is considered. The main types of refiner, their design characteristics and internal components are described. Guidance on the type of fillings suitable for different fibres is provided.

Section 3 identifies types of installation and their layouts. The refining of multi-component furnishes, series versus parallel operation and normal operational settings are described.

Section 4 investigates operational parameters and their influence on energy use.

Section 5 describes methods of control to optimise energy use.

Section 6 discusses maintenance and performance review.

Section 7 provides a contact list of appropriate manufacturers.

2. BACKGROUND TO REFINING

2.1 The Practice of Refining

Refining in papermaking is a process for mechanically modifying the properties of the cellulose fibre raw material. This is achieved by introducing a fibre/water suspension into a narrow space (of the order of a few thousandths of an inch (tens of microns)) between two metal surfaces rotating in respect to one another. These metal surfaces have a pattern of bars and grooves designed to generate pressure waves that cause fibres to impact against each other, and also against the metal surfaces.

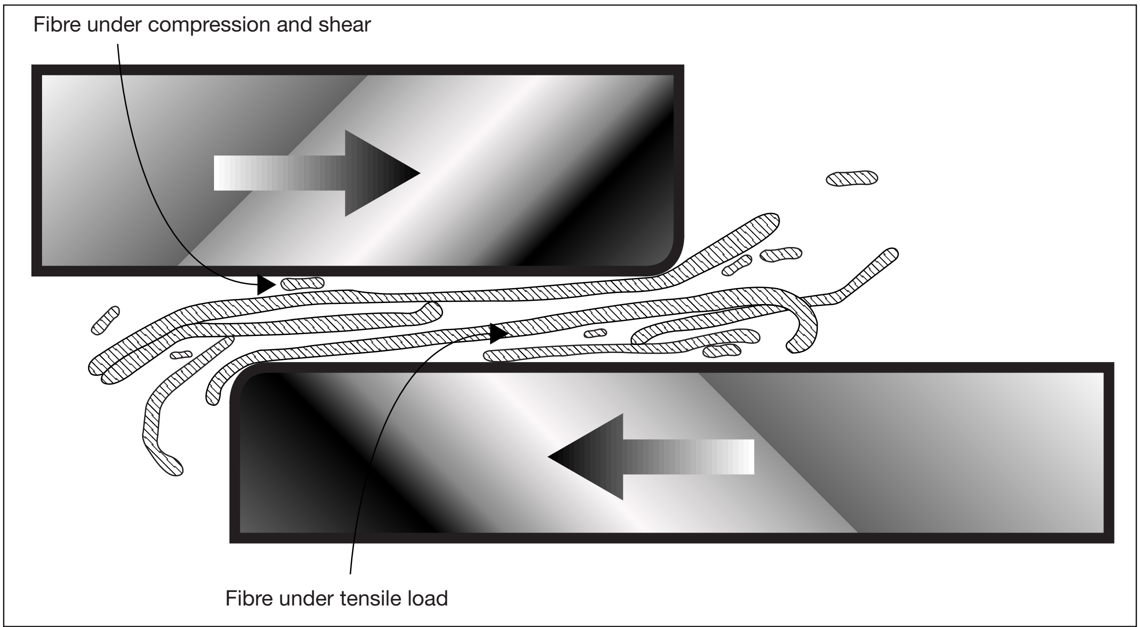

Fig 2 Impression of fibres trapped between passing stator and rotor bars

These impacts 'beat up' the fibre and change the way it bonds in the final product. The extent of these changes is influenced by the way the refiner is designed and run. The following variables are particularly important:

- refiner gap;
- bar/groove pattern of rotating surfaces (known as refiner 'fillings' or 'tackle');
- speed of rotation;
- consistency of fibre suspension (stock);
- mass flow rate of stock (residence time of fibre in refiner).

For minute-to-minute control, the operator is always able to alter the refiner gap. As the gap decreases, the refiner has a greater resistance to rotation and so requires greater power from the motor to turn. Some practical considerations that limit the reduction of the gap are:

- the available power from the motor;
- the tendency for the refiner to clog as the gap is reduced too far;
- breakdown of the fibre mat, causing the plates to clash.

Refiner fillings are replaced at regular intervals as the surfaces wear, and a different design can be selected usually within a few months. The other parameters can often be difficult to alter quickly, because of the limitations of the equipment and the demands of the rest of the paper machine: changes in these parameters may require fundamental design changes.

2.1.1 *Primary Effects of Refining*

This Good Practice Guide provides practical advice on fibre refining, describing only briefly the theoretical aspects of the refining process. Current knowledge of the fundamental changes occurring in fibres during beating or refining has been reviewed by a number of researchers and is readily available (see Appendix 1). Within this practical context, the primary effects of refining are:

- fibre cutting or shortening (which can be measured optically or by the increase in weight of the short fibre fraction);
- the production of partial fibre fragments ('fines') and the complete removal of parts of the fibre wall, creating debris in suspension;
- external fibrillation - the 'shredding' of the fibre wall creating smaller fibrils, extending from the fibre but still attached to it. This increases the degree to which the fibres can 'tangle' together and bond, and thus affects the strength of paper manufactured. However, it can also close up the pore structure of the paper, making drainage and water removal more difficult (Fig 3).

From the required product properties, the papermaker must define the degree of fibre modification needed, and then achieve this via appropriate refining. Conventionally, cutting and fibrillation are the desired effects of refining; the correct balance of these properties having the most significant impact on the energy used to produce a given product.

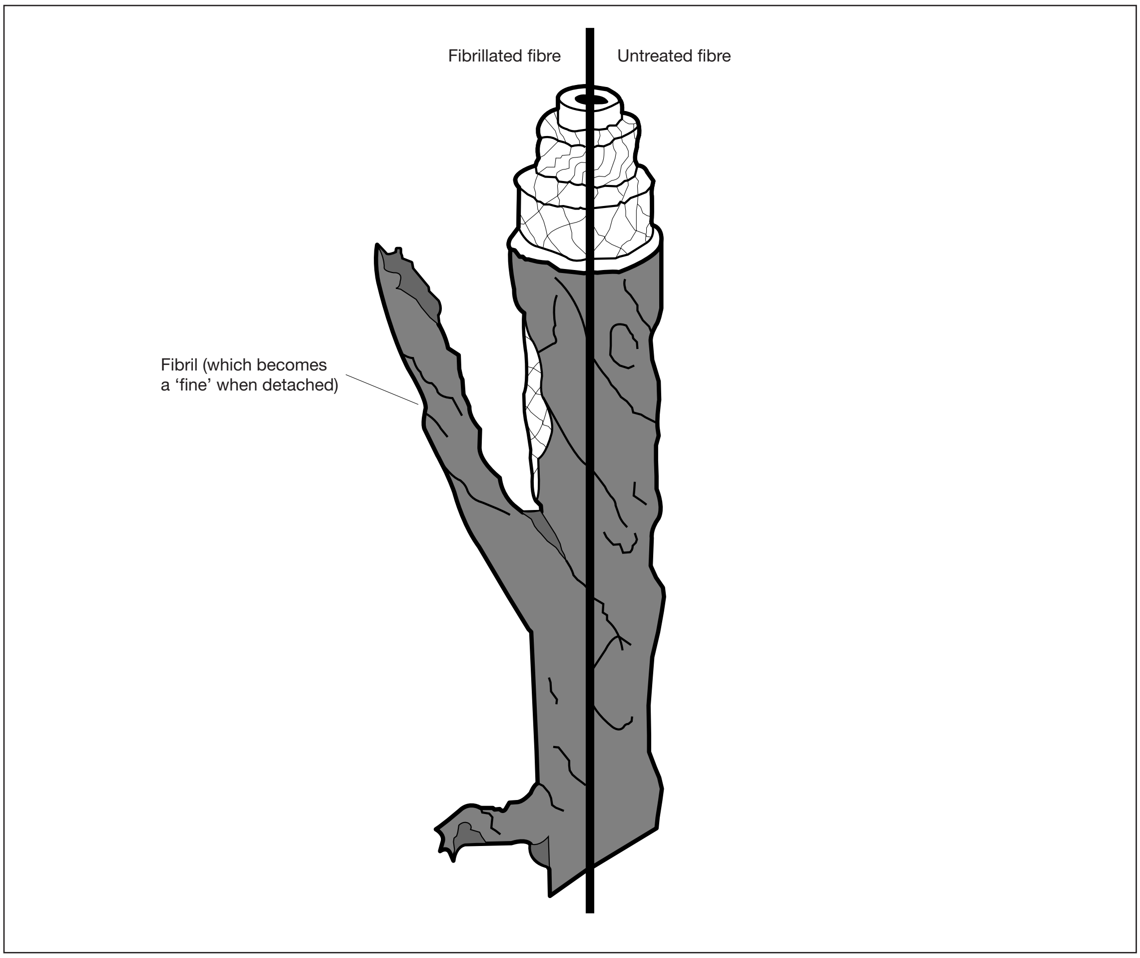

Fig 3 Structure of fibrillated fibre

2.1.2 *Some Points of Refiner Theory*

Until recently refining has been considered more an art than a science. Refiners were often selected primarily on the basis of cost to treat a specified throughput, with fillings chosen by manufacturers based on information relating to the fibre development required to achieve

product specification. In operation, the load on refiners was simply adjusted according to the results of tests on the paper produced - a control method subject to a significant delay, depending on machine speed and paper roll size. Wetness measurements by Schopper Reigler or Canadian Standard Freeness methods were sometimes used, providing a quicker feedback of refiner treatment if performed regularly (once per chest or batch) or controlled by feedback systems (see Section 5). The operational power levels of a refiner were usually monitored by an ammeter, which triggered an audible warning requiring human response. Actual power measurements were made only infrequently.

Specific Energy Consumption (SEC) or the 'kWh per tonne of dry pulp allowing for the no load' is a relatively new concept which enables an operator to set refiner load by referring to previous manufacturing records of product. In using this parameter the reasonable assumption is made that if the useful power input is controlled according to the quantity of fibre passing through the refiner then the treatment should be consistent.

The opportunity to pay closer attention to fibre development in relation to energy use came with the evolution of formulae describing the refining process in a quantitative way. These formulae are not based on rigorous theory but help to visualise and quantify the refiner process. They are particularly useful at giving a rough comparison between alternative treatments, though their use is limited to the more common grades of paper and board.

There are several theories that describe the severity and number of impacts received by a fibre slurry passing through a refiner. The simplest to use is Specific Edge Load (SEL) which measures energy applied to the fibres between rotor edge and stator edge. It is defined as the ratio of net load and bar cutting edge length (CEL) per second and is measured in joules per metre:

$$\text{SEL} = 60 \text{ x } \frac{\text{Total kW} - \text{No load kW}}{(\text{CEL km/rev}) \text{ x } (\text{revs/s})} \text{ J/m}$$

SEL is considered to produce a figure related to the tendency of the refiner to cut fibres. Typical SEL figures for short fibres range from as low as 0.2 J/m for the treatment of weak hardwood and recycled fibre, up to 1.5 J/m for very strong fibres. The values of SEL for softwood and other long fibres usually range from 1.5 J/m for weak fibres up to 3.0 J/m for strong fibres.

A second popular parameter is Specific Surface Load (SSL) which measures the energy applied to fibres from rotor surface to stator surface. It is defined as the ratio of net load and surface impact area per second and is measured in joules per square metre.

$$\text{SSL} = 60{,}000 \text{ x } \frac{\text{Total kW} - \text{No load kW}}{(\text{Surface contact area m}^2\text{/rev}) \text{ x } (\text{revs/s})} \text{ J/m}^2$$

where surface contact area is calculated as the product of bar CEL in km and average width of impact (taking account of the bar angle) in mm.

SSL attempts to measure the degree of pressure to which fibres are subjected, it being assumed that this relates to the amount of fibrillation occurring. The values for SSL that apply in typical conditions vary with the freeness development required for the pulp. SSL values of 800 J/m^2 or higher may be reached for heavy softwood development, while for hardwood SSLs will be between 300 J/m^2 and 350 J/m^2.

SEL and SSL are related to each other by the expression:

$$\text{SSL} = 1{,}000 \text{ x } \frac{\text{SEL}}{\text{average width of impact in mm}} \text{ J/m}$$

Refiner manufacturers will be able to provide figures for cutting edge length and surface contact area appropriate to different types of filling, from which it is simple to calculate SEL and SSL. The values of both SEL and SSL increase with bar width and groove width. Examples of this relationship for the standard range of disc refiner fillings are provided in Table 1.

Table 1 Effect of changes in bar dimension (24 inch or 600 mm filling)

Filling dimension (mm) groove - bar width	**Filling dimension (1/16 inch) groove - bar width**	**CEL (km/s)**	**SEL @ 200 kW net (J/m)**
2.2 - 2.2	1.5 - 1.5	308	0.67
3 - 3	2 - 2	142	1.41
4.5 - 4.5	3 - 3	77	2.6
6 - 6	4 - 4	50	4.0

Correct SEL and SSL reduce SEC for the required paper properties. The higher the SEL the greater the cutting action; the lower the SEL the more the fibre is fibrillated.

The following variables influence SEL and SSL, and hence SEC:

- Refiner motor power (kW) - this increases with reduced refiner gap within the limits determined by available power of the motor and avoidance of excessive pressure on the fibre mat.
- No Load power (kW) - measured by backing off the refiner gap, usually with water running through. The value depends closely on refiner design and condition of fillings, and increases with rotation speed.
- Type of refiner fillings, i.e. pattern, angle, bar length and width of the fillings - these directly affect cutting length and surface contact area.
- Rotation speed - usually fixed for the motor.
- Consistency of stock - manufacturers usually recommend a preferred range based on pilot plant work, higher for short fibres (4.5 to 5.5%), lower for long fibres (3.5 to 4.5%).
- Volumetric flow forward - determined by machine demand with throttling back and re-circulation used to keep the refiner to required operating conditions.
- Filling condition.

2.1.3 *Application to Paper Grades and Furnishes*

SEL theory can be applied to the production of various common grades of paper. By adjusting refining parameters, optimum SEL for the desired mix of paper and fibre properties is achieved, while simultaneously minimising energy use. Whatever the product requirements, the desired properties can be imparted by furnish selection and correct refining. The science of refining is to ensure that this is done with the right equipment under the right conditions. **Only then will energy use be optimised.** In practice, however, the various requirements are diverse and contradictory. For example:

- security papers require short, cut fibres to achieve good watermarking, but also longer, fibrillated fibres to provide the strength and handle of high quality paper;
- coating papers incorporate the high strength of relatively highly-refined, fibrillated fibres to provide runnability in the coaters, but the demands of dimensional stability require a moderate degree of fibrillation to reduce shrinkage on contact with aqueous coating mixes;
- glassine and tracing papers must possess the water holdout and translucency of highly fibrillated fibres, but also the high tear provided by stock with little refining and long fibre length.

2.1.4 *Energy Use by Grade*

Refining energy use varies by product, with filter and blotting papers requiring least energy input and tracing papers requiring the highest. Some typical energy consumptions are shown in Table 2.

Table 2 Typical energy use by product

	Specific energy consumption* (kWh/tonne)	**Gross energy consumption** (kWh/tonne)**
Printings and writings	60 - 100	90 - 300
Coating papers	100 - 150	175 - 350
Carbonless papers	150 - 200	250 - 500
Glassine/greaseproof	450 - 600	600 - 1,000
Tracing	800 - 1,200	1,600 - 3,000

* *SEC is derived from gross energy consumption minus the no load power, which is the power that is taken up by mechanical drag and turbulent forces and is therefore not available to treat the fibres.*

** *This figure depends on the refiner efficiency.*

The degree of refining required to achieve the desired fibre properties depends broadly on the SEC, defined above, in addition to the refiner efficiency which is a function of design, plate wear and general condition. The lower the refiner efficiency, the more actual gross power it will consume to achieve the same degree of refining.

The potential energy savings are great for many fibre refiners, but methods of actualising this potential vary in complexity and cost. Many refiners are incorrectly sized or not well maintained, which results in a high no load power that reduces refiner efficiency.

2.2 The Papermaking Process

The manufacture of paper is not a single process but a series of linked and interdependent operations. These operations fall into three main areas: stock preparation, wet end and dry end processes. Energy use varies for each process and can be considerable. Apart from drying, the refining process consumes more energy than any other. The interrelationship of refining with the other papermaking processes can be modelled as shown in Fig 4.

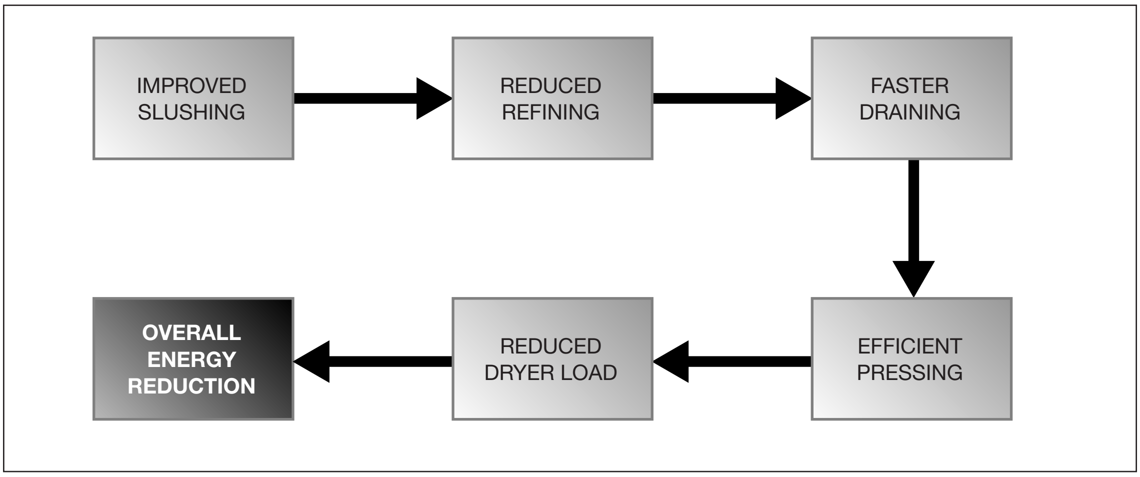

Fig 4 Interrelationship of papermaking processes

2.2.1 *Slushing*

Up to 60 kWh/tonne of electrical energy can be used to break up dry pulp or recycled fibres in a pulper. Materials can be pulped at a range of consistencies from low (4 - 6%) through medium (6 - 10%) to high (10 - 15%), depending on the application.

The efficiency and duration of slushing influences the amount of subsequent refining required. If stock is not well dispersed, leaving fibre bundles, more energy will be required in refining to achieve the desired effect. Slushing for a longer period than is needed simply to break up bales can often be beneficial, especially with short fibres.

The SEC for pulping is four or five-times less than for typical refining. It may, therefore, be advisable to slush more than is necessary simply to disperse fibre bundles while useful fibre development occurs. The more fibre development that takes place before refining, the less energy needed to achieve the desired result. If slushing is continued for too long, however, the rate of fibre development diminishes and a point can be reached where the activity in the pulper reduces, as can be witnessed by a slowing up of the vortex.

The most energy efficient way to run a pulper can be determined by applying the Energy Optimisation Test (EOT). This method depends on the observation that continued slushing steadily increases fibre development. For example, in one commercial pulper a mix of hardwood pulps increased in tensile strength from 14 to 30 Nm/g over a period of ten minutes slushing, while burst increased from 0.45 to 1.1 kPa.m^2/g.

The EOT is a simple method to determine the optimum duration to slush any particular pulp, and can be carried out in any mill laboratory. It may be related to test parameters appropriate to the product being manufactured, and involves little more than testing hand-sheets of samples from the mill pulper taken over an extended period of slushing. The results are compared to those from a standard Valley Beater test on the pulp and a simple energy parameter determined to identify the optimum slushing period.

The technique has been applied in mill situations with savings of up to 20% of pulper energy achieved simply by altering slushing time within limits imposed by production requirements. The procedure and the background to development and verification of the EOT is described in detail in General Information Leaflet 53, *Optimising energy use in pulpers and refiners*, available free through the Environment and Energy Helpline on 0800 585794.

More effective slushing can reduce refining energy use

2.2.2 *Forming*

A paper machine that makes a well-formed sheet can yield stronger paper for less refining. In general, the more energy that is used refining stock, the harder it is to drain. This results in wetter web entering the presses, increasing the energy needed to press and dry. Correct refiner use and selection can therefore save both refiner and dryer energy.

Improved formation can reduce refining energy use

2.2.3 *Pressing and Drying*

In most instances, increases in refining energy close up the pore structure of the paper. This means that water is held more tightly in the sheet and more energy is needed to remove it. In the press section, this may result in a higher mechanical energy consumption to remove the water or, more likely, increased moisture content levels in the sheet leaving the press. Consequently, not only is there more water to be evaporated in the drying section, further increasing energy use, but evaporation also becomes more difficult, reducing the upper limit on production rate in the dryers.

An increase in refining energy increases drying energy

Attention to detail and correct fillings in refiners will enable desired paper properties to be obtained without affecting drainage properties. In some cases, savings in drying energy can be made by reducing the amount of refining required.

2.3 Main Types of Paper Mill Refiner

The two main types of refiner are the conical (see Section 2.3.1) and the disc refiner (see Section 2.3.2). The Beloit refining manual states that: '... within certain limits, when a refiner is properly applied, there is not a great difference between conical and disc refiners regarding their ability to develop fibres. In other words, a fibre cannot read the label on the refiner and does not know if it is in a disc or a conical refiner. It is aware of only two things - how many times it is hit and how hard it is hit each time.' ***Choice of refiner must consider the correct treatment for the required product.*** Only when this primary consideration is satisfied should other, nonetheless important, considerations such as reliability, efficiency, etc. be addressed.

2.3.1 *The Conical Refiner*

Conical refiners, operating as continuous throughput units, treat fibres by rotating a conical plug in a mating shell. This permits minor adjustments for clearance between working surfaces, while the rotating plug tends to centre as it turns in the stock which serves as a lubricating medium. There is only one treatment zone, which is considered an advantage to keeping treatment surfaces parallel. Normally surface alignment can be maintained but, when two mating surfaces are not an exact fit, point contact results. Consequently, power use increases but, as the bars are no longer in contact, little fibre treatment occurs. A schematic of a conical refiner is shown in Fig 5.

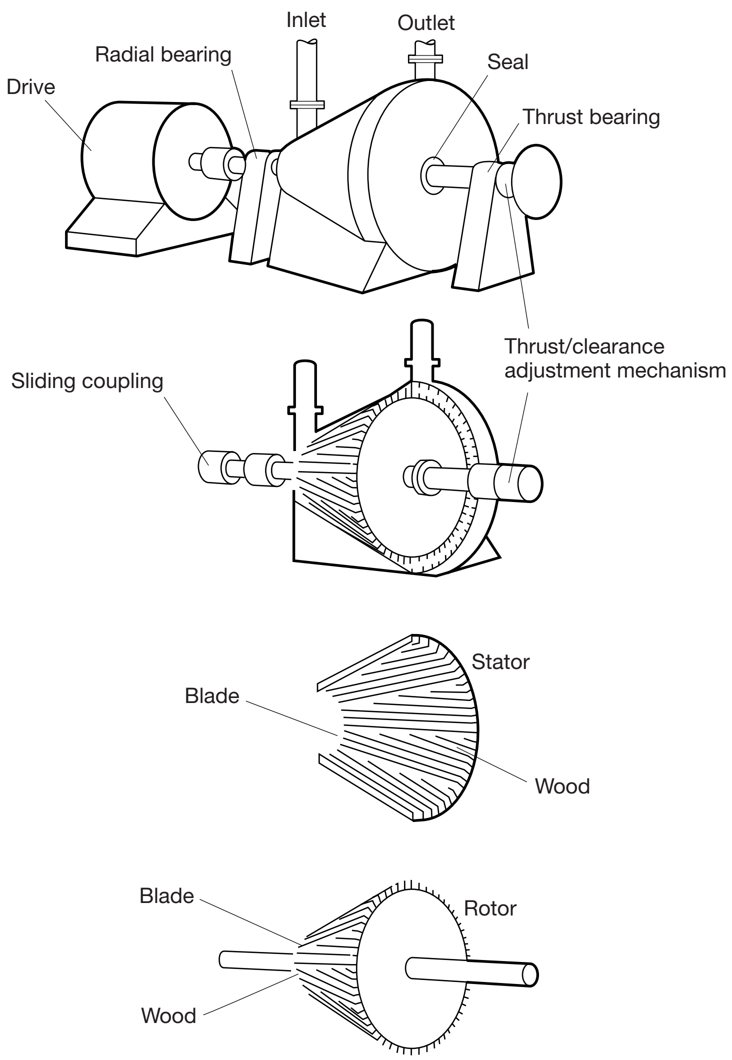

Fig 5 Schematic of the conical refiner

2.3.1.1 *Low Angle Conical Refiner*
The low angle refiner, which is manufactured by a number of companies, is still found in many fine paper mills, but has a number of drawbacks compared with modern conical and double disc refiners. The Jordan refiner is shown in Fig 6. Certain parameters of this refiner are not optimised for low energy use:

- high no load power resulting in low operating efficiency - less than 50% in many installations;
- lack of flexibility - a limited range of fillings available;
- fillings tend to have few bars so refining intensity is high and unsuitable for short fibred pulps.

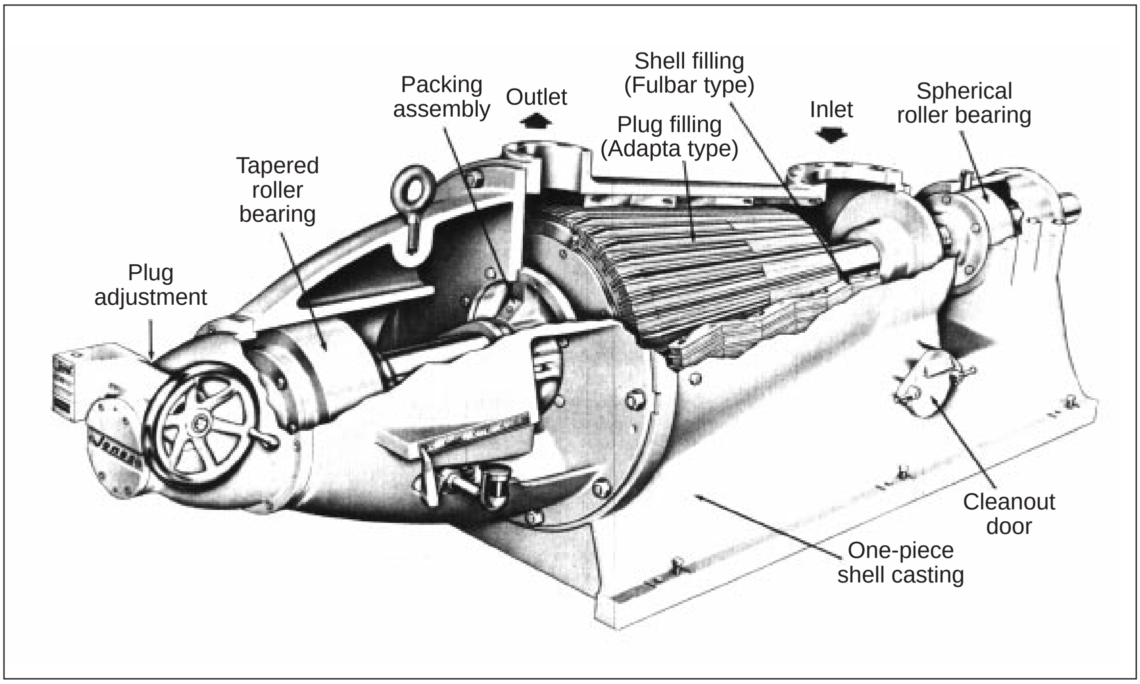

Fig 6 Jordan refiner

2.3.1.2 *Wide Angle Conical Refiner*
The most widely used version of this type of refiner is the ‘Claflin’ refiner, which has an increased cone angle of 60°. This refiner is found in many mills and has a reputation for robustness. A particular feature of the refiner is the ‘Develomax’ filling, which simulates the action of a basalt lava filling, giving a very low SEL. This type of filling is used on many tracing and glassine paper producing machines. The refiner and internals are shown in Fig 7.

Fig 7 Claflin refiner

2.3.1.3 *Conflo Conical Refiner*

The Conflo refiner is a recent design of conventional conical refiner. The advantages claimed for this refiner are low no load power and a long refining zone. The outer casing of the refiner is also the shell, which reduces the time required to change fillings. The groove depth is relatively shallow, reducing the no load arising from pumping. The Conflo refiner is shown in Fig 8.

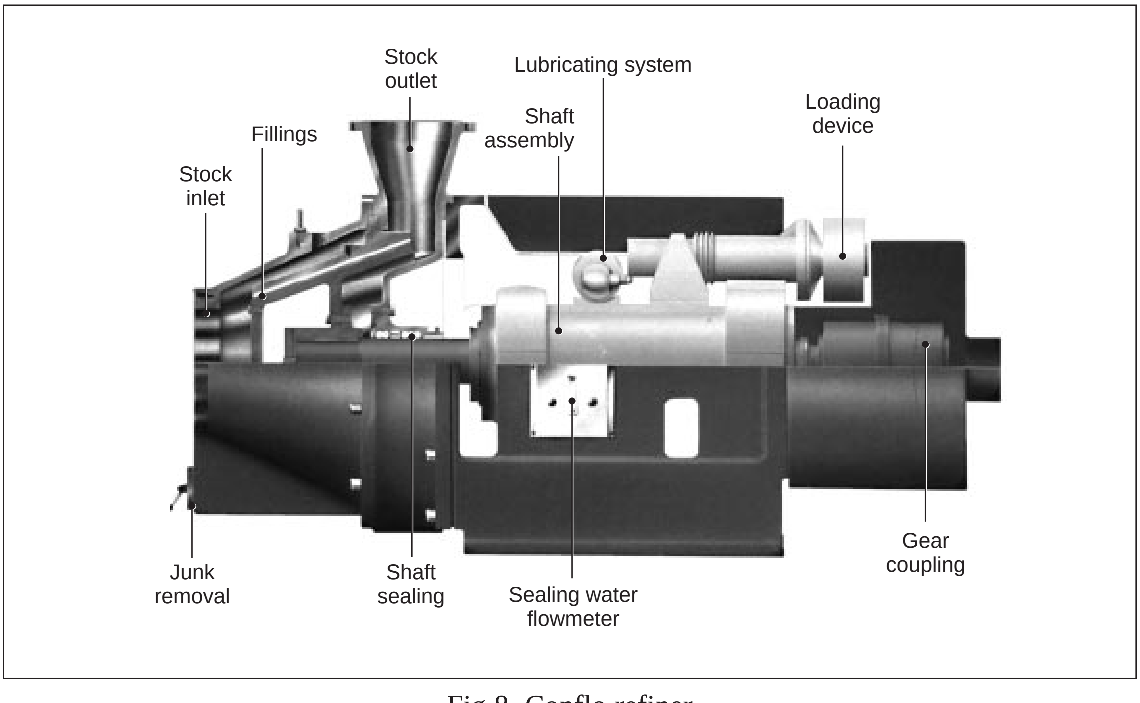

Fig 8 Conflo refiner

2.3.1.4 *TriConic Refiner*

The latest development in conical refiners is the 'TriConic(r)' conical refiner, currently being tried out in three mills. The system is based on the tri-disc design converted to cone and shell with double flow capabilities. The refiner incorporates a wide angle, double-faced rotor and two stator fillings, which increase performance and capacity while claiming to reduce the energy requirement considerably.

This refiner combines the long bar length of the conical refiner with the two zones of the double disc refiner. Effectively the smallest version has the same area as a 34 inch double disc refiner and the largest as a 46 inch double disc refiner. This means that for a given size of conical refiner having the same rotation speed, the CEL will be up to three-times higher, allowing a much lower SEL.

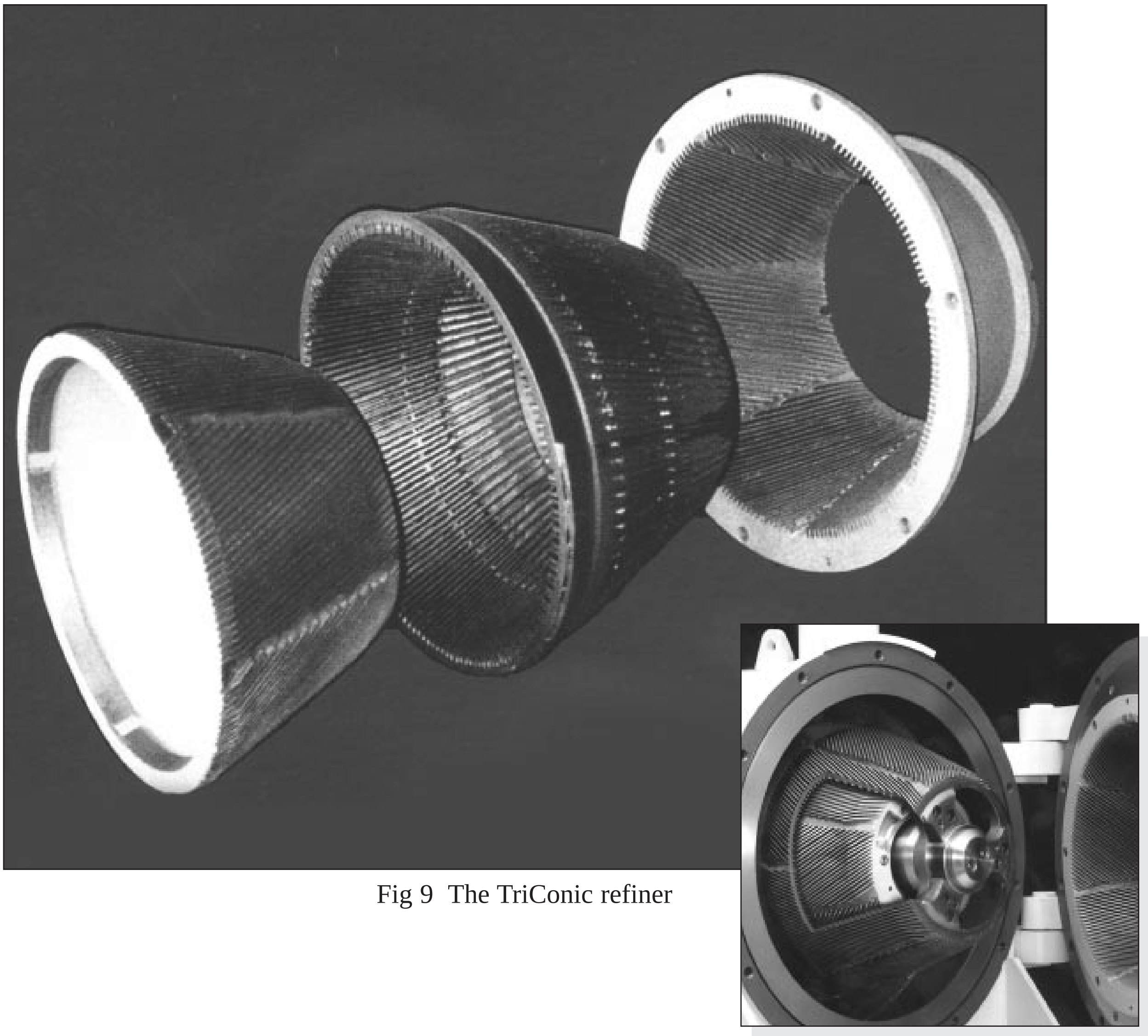

Fig 9 The TriConic refiner

2.3.1.5 *Comparative Efficiencies of Conical Refiners*
Typical operating parameters (as supplied by manufacturers) for different conical refiners of similar throughput are compared in Table 3.

Table 3 Operating characteristics

	Low angle	**Claflin**	**Conflo**
Motor power (kW)	263	250	200
No load power (kW)	132	62	35
Rotation speed (rpm)	419	360	740
Efficiency (%)	50	75	82
Cutting edge length (CEL) (km/s)	30 - 80	30 - 150*	23 - 98

** Excluding 'Develomax' filling*

Table 3 shows that the Conflo has a higher rpm motor which increases the CEL and, in spite of the higher rotation speed, it has the lowest no load. The Conflo and Claflin refiners offer a range of fillings.

Case History 1 Replacement of Wide Angle Conical Refiners

The refining system on a UK fine paper mill machine had four wide angle conical refiners. In normal operation, three refiners were used to treat the stock. The three refiners were normally operated at maximum power and required 282 kWh/tonne (gross) to supply 157 kWh/tonne (net). The refiners were considered to be oversize for the flows used and so replacements were considered.

After initial trials, the original four refiners were replaced by three Sunds-Defibrator JC-01 refiners, two of which were sufficient to treat the stock to achieve the same properties. Energy consumption for the new system was 167 kWh/tonne (gross) to supply 108 kWh/tonne (net), an overall saving of 115 kWh/tonne. **At a cost of 3p/kWh, this represents a cost saving of £4.45/tonne, or £200,000/year for a medium-size (50,000 tonne/year) mill.**

2.3.2 *The Disc Refiner*

2.3.2.1 *Double Disc Refiner*
The double disc refiner offers increased refining capabilities (as a result of two treatment zones) and greater energy efficiency than standard conical refiners. It is also extremely flexible in operation due to the wide range of plate designs available. Standard fillings provide (for similar sizes) a similar range of bar length to modern conical refiners. The double disc refiner provides large numbers of short bar impacts, whereas the conical refiner offers fewer long bar impacts. A schematic of the double disc refiner is shown in Fig 10.

The two zones of the double disc refiner allow a high energy input per refiner for a given SEL. This means that, in theory, one double disc refiner can replace a number of low angle refiners.

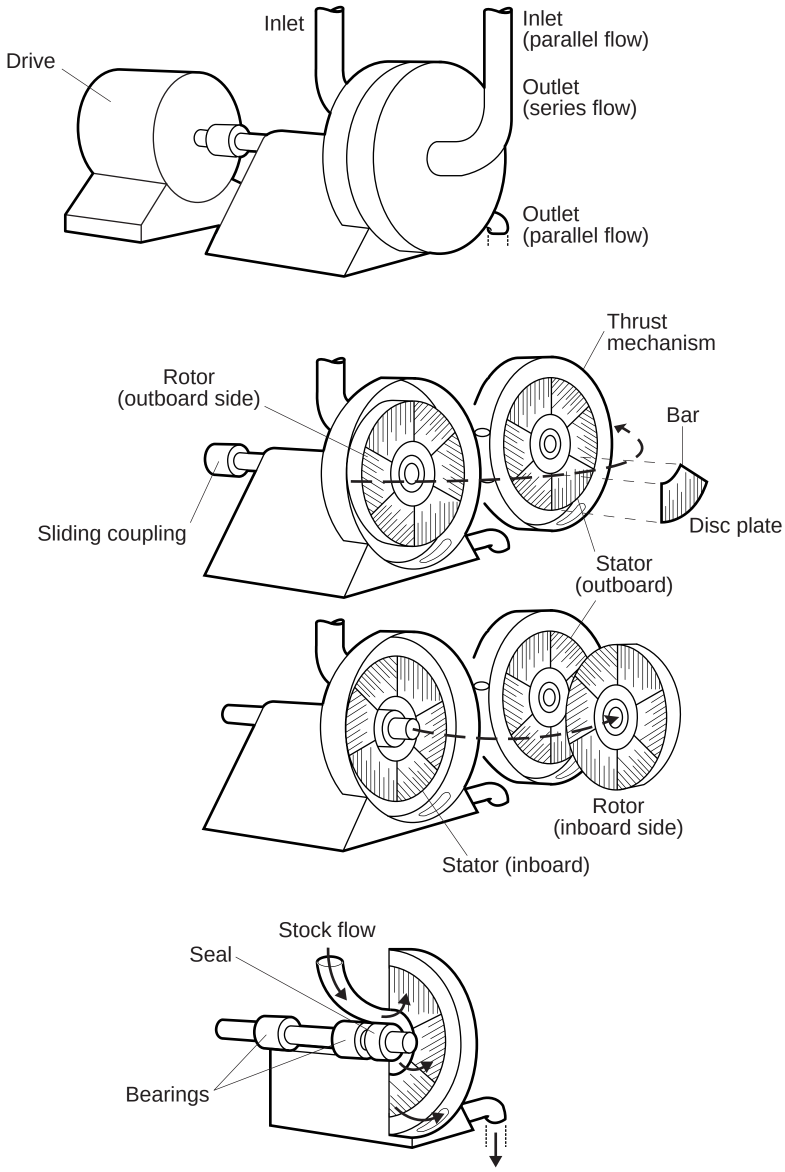

Fig 10 Double disc refiner

Example

To treat stock to a SEL of 1.0 J/m, using a net energy input of 100 kWh/tonne to achieve the required properties for a printing paper on a 1.0 tonne/h machine, would require four low angle conical refiners operating at 220 kWh/tonne (gross).

One 24 inch diameter double disc refiner would provide the same net energy with *improved* properties operating at 175 kWh/tonne (gross), a saving of 45 kWh/tonne. Similarly, a modern conical refiner of equal size supplies the same net energy at 135 kWh/tonne (gross), a saving of 85 kWh/tonne on the low angle conical refiner.

2.3.2.2 *Monoflo and Duoflo Configurations*
Having two zones, a double disc refiner can be internally configured for series or parallel operation, known as monoflo and duoflo respectively. In monoflo operation, stock flows through each zone sequentially; while in duoflo, stock flows through each zone simultaneously doubling refiner capacity. The various internal configurations are shown in Fig 11.

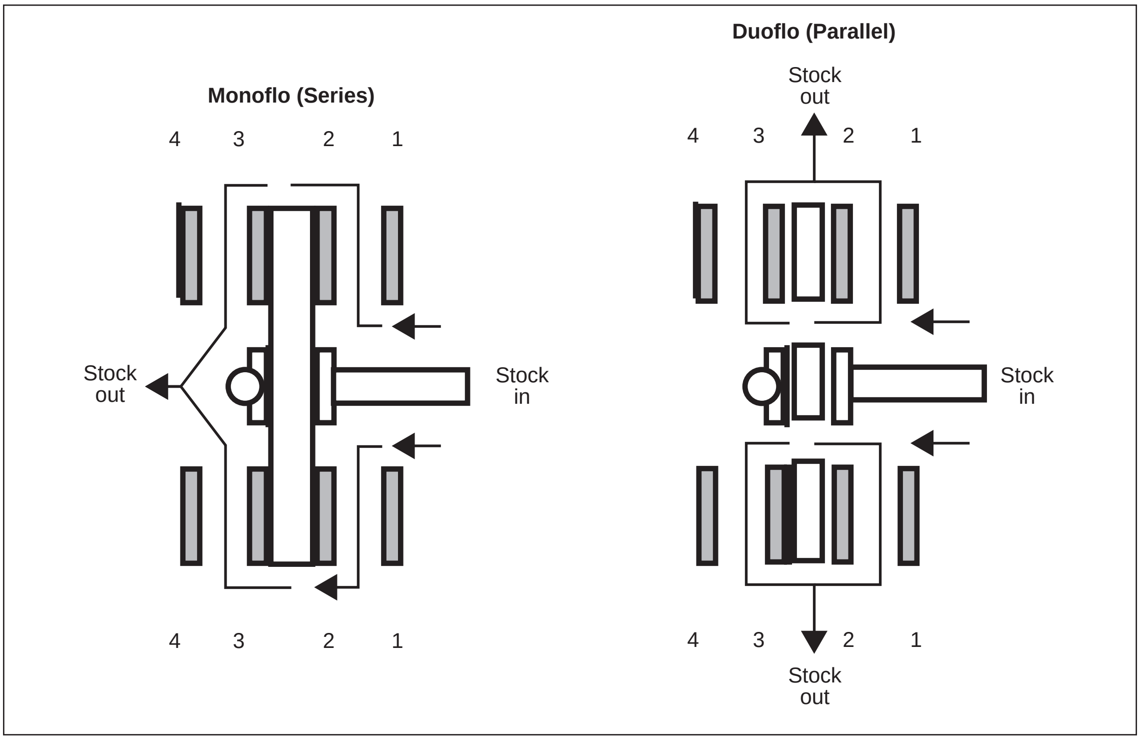

Fig 11 Various configurations for a double disc refiner

By blocking or unblocking the passages through the rotor, a double disc refiner configuration can be changed between duoflo and monoflo. Flow change is necessary when fibre usage changes, e.g. increased hardwood or reduced softwood content, to allow modification of flow characteristics for each refiner. With duoflo operation it is easier to maintain equal gaps in the two zones.

2.3.2.3 *Multi-Disk Refiner*
It is generally considered that an SEL of less than 0.5 J/m is needed to treat short fibred pulps, such as virgin hardwoods, mechanical pulps and some wastepaper grades. Although this intensity can be achieved with standard conical refiners, the operation is not energy efficient.

The formula for SEL shows that low values in a particular refiner can only be achieved by increasing the CEL of the bars or the rotation speed, or by reducing the net power input. Increasing the CEL of fillings is limited by the number of bars of finite width it is possible to pack into the refiner. Increasing rotation speed is generally limited by design and, even where possible, increases no load, thus making the operation less efficient.

Reducing the net power input for a constant or increased no load is costly in energy terms. In addition, to develop the fibre properties adequately the net specific energy input is effectively fixed, so if net power in kW is reduced there must be a corresponding decrease in flow rate. Since the flow rate depends on the production rate of the paper machine, this implies that more refiners are needed to achieve the desired effect.

Example

Consider a system treating 4 tonne/hour at a net energy of 100 kWh/tonne, using the finest fillings available and at the same rotation speed.

- A typical 24 inch double disc system with an SEL of 0.4 J/m would need two refiners in parallel at 160 kWh/tonne (gross);
- A typical conical system would need four refiners at 150 kWh/tonne (gross).

These figures imply very low power applied to each refiner, e.g. 37.5 kWh/tonne to the conical refiners, which is a very inefficient use of motor power. Apart from inefficiency, the capital costs of such systems would be prohibitive.

The first production solution to this problem was the 'Multi-Disk' refiner. For the same disc size and rotation speed this design overcomes conventional limitations by increasing the number of bars in the refiner, by introducing more rotating and stationary elements in place of the single two-sided rotor and pair of stator plates in a conventional refiner (Fig 12). Retrofit of existing double disc refiners is possible.

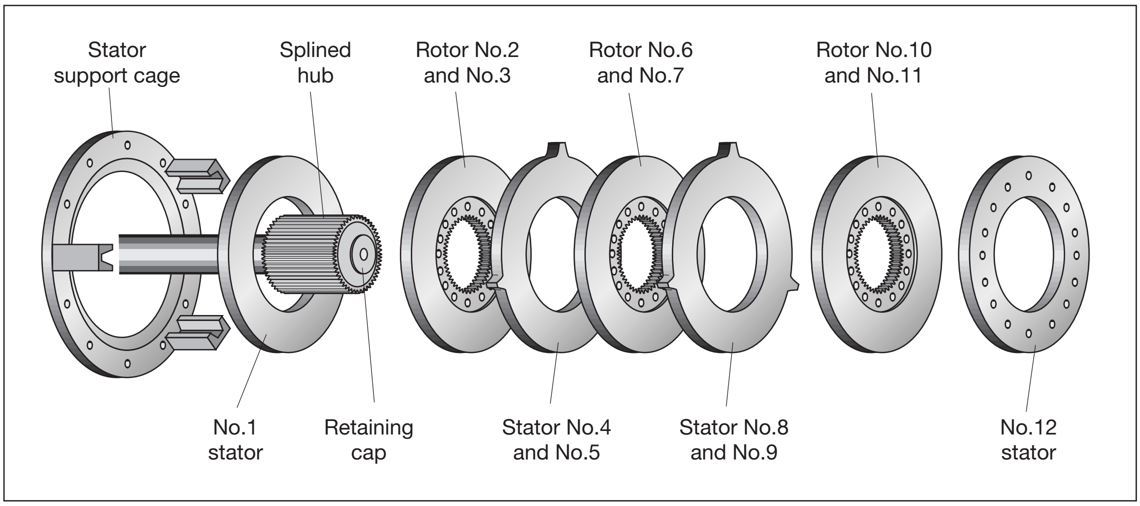

Fig 12 Multi-Disk refiner schematic

The Multi-Disk refiner consists of alternate stationary and rotating elements. Stock enters the machine through an inlet port at the centre of the machine housing along the axis of the main shaft. Both rotors and stators are capable of axial movement so that stock can distribute between the refining interfaces. Flow control is important and must be correct to ensure that the refining zones give equal treatment.

The double disc refiner has two zones, whereas the Multi-Disk can have up to eight. This results in an intensity that is 25 - 30% of the normal lower limit of a double disc refiner. In addition, the spread of power across a multiplicity of zones is claimed to extend filling life.

The Multi-Disk refiner is used in the USA for the post-refining of thermo-mechanical pulp and for refining hardwood. Table 4 shows the advantages gained by using a 24 inch Multi-Disk refiner instead of a standard double disc refiner of similar efficiency at 3.5% consistency for bleached Northern Hardwood kraft.

Table 4 Multi-Disk versus double disc

	Multi-Disk (0.35 J/m)	**Double disc (1.4 J/m)**
Net energy (kWh/tonne)	59.5	76.6
Gross energy (kWh/tonne)	50	105
Canadian Standard Freeness (ml)	300	300
Burst factor (kPa.m^2/g)	36	27
Bulk (cm^3/g)	1.53	1.53
Tear factor (mN.m^2/g)	79	69.5
Breaking length (km)	6.2	5.1

Case History 2 Multi-Disk Refining at Bridgewater Mill

A Multi-Disk unit was installed in 1996 at Bridgewater Mill as part of a programme to increase the amount of de-inked pulp used for newsprint production. Although several other changes were made to the stock preparation system at the same time, the single Multi-Disk unit with three 38 inch rotating elements effectively replaced three existing double disc refiners. The results were independently monitored under the Energy Efficiency Best Practice Programme and have been published in New Practice Final Profile 99, available free through the Environment and Energy Helpline on 0800 585794.

After some initial problems during commissioning, operation settled down and performance was compared before and after installation over a twenty-week period. A detailed comparison was also made when running a tightly specified 45 gsm newsprint, during which measurements and samples were taken over three separate makings. Energy and cost savings of over 30% were identified, although not all can be directly attributed to installation of the Multi-Disk. Use of a greater proportion of de-inked pulp in place of chemi-thermo-mechanical pulp and alteration of the disc filter sweetener to unrefined stock made a direct comparison of fibre development difficult.

Analysis of samples at the Fibre Technology Association, however, concluded that the refined pulp had enhanced bulk, air permeability and smoothness relative to the original two-stage double disc system in the main stock stream, although strength properties were not developed to the same degree. The refined pulp stock appeared to be more uniform and had a higher freeness with the potential for increased machine speed. Maintenance costs for plate changes were projected to be significantly higher than for the double discs but nonetheless a simple payback was calculated of some eighteen months, much less if the increased output is included.

2.4 Selection of Fillings

The furnish used in papermaking almost always consists of a mixture of fibre species. These can be wood or non-wood fibres with different methods of extraction, each of which will have different refining needs. The fitting of correct fillings enables considerable energy savings to be made. The effect of different kinds of filling on the refining of hardwood pulp is shown in Fig 13, where the nomenclature (2-2-4, 1.5-1.5-3, etc.) stands for the bar and groove dimensions in sixteenths of an inch. The smaller the number, the finer the filling, the gentler the action and the lower the energy use.

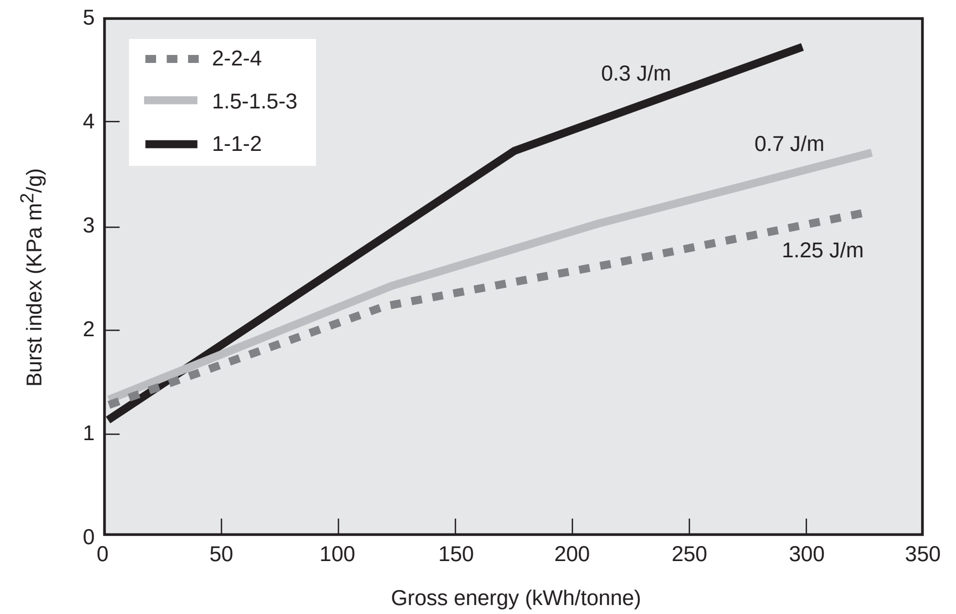

Fig 13 Impact of fillings on energy use for hardwood pulp

The fillings in the following Sections are suggestions only: *always consult with the manufacturer before proceeding.*

2.4.1 *Non-wood Fibres*

The commonest non-wood fibre is cotton, normally used as linters. Other types are hemp, esparto, jute and flax. The fibres are characterised by their length and a tendency to form tight fibre clumps when treated in high-speed refiners. For this reason it is common to reduce the fibre length in a beater before refining, normally using low speed conical refiners. Suggested fillings are therefore at the coarser end of the range, typically having bar and groove dimensions of $^1/_4$ inch (6 mm) or greater. Refining consistency should be as low as is possible without causing plate dash.

2.4.2 *Wood Fibres (Softwood)*

Softwood fibres are relatively long, tough fibres, that require a moderately harsh treatment. In SEL terms, an intensity of 2.0 J/m is considered good practice with an operating range of 1.5 - 3.0 J/m. In this case, optimum refining is considered to be that which gives the best property balance. To give a well-formed sheet the softwood needs to be cut as well as fibrillated for strength. Suggested filling dimensions are between $^2/_{16}$ inch and $^3/_{16}$ inch (3.0 to 4.5 mm) bars and grooves. All of the modern refiners are suitable for refining softwood.

2.4.3 *Wood Fibres (Hardwood)*

Hardwood fibres, e.g. eucalyptus, birch and mixed hardwoods, have been used as filler pulps with little refining treatment. Current practice, however, is to treat hardwoods to develop their maximum potential. To do this, the refining must be gentle and intensities of much less than 0.5 J/m are desirable. The finest fillings are necessary, with typical dimensions of $^1/_{16}$ inch to $^{1.5}/_{16}$ inch (1.5 to 2 mm) or less. The need for very low intensity refining requires careful consideration of refiner type if energy efficiency is to be maintained.

2.4.4 *Mixtures*

Furnishes are commonly mixtures of those fibres described, each of which requires very different treatment (see Section 3) and so should, whenever possible, be treated separately. However, especially in smaller machines, where the fibre flows would be too low to have separate lines, mixed refining is the only option. For mixed furnishes good compromise fillings have dimensions of $^2/_{16}$ inch to $^3/_{16}$ inch (3 to 4.5 mm).

2.4.5 *Secondary Fibre*

The increasing use of secondary fibre poses a different kind of problem, in that the fibre can consist of mixtures of both chemical and mechanical pulps made from wood and non-wood fibres. It is normal to use these fibres without further refining treatment, but there is now a trend towards further refining as methods of 'upcycling' are sought. The temptation is to treat the fibre as though it were a hardwood, i.e. with very gentle treatment, but the already refined recycled fibre becomes over-refined. The current best practice, as a generality, is to treat the fibre at a medium to low intensity (0.7 to 1.0 J/m), depending on the type of waste. A good office waste will be able to cope with more treatment than newsprint or OCC.

Case History 3 Performance of Different Fillings

The importance of correct choice of fillings was highlighted in a direct comparison of several different designs made on a production machine at the Inveresk Carrongrove board mill. The stock preparation system of this machine comprises a single pulper, which alternately slushes bales of softwood and a hardwood blend that are fed to separate dump chests and then in each case to one of a pair of parallel refiners.

The fillings selected for comparison are shown in Table 5.

Table 5 Comparison of fillings

Filling designation	Description	Used for	SEL (J/m)	SSL (J/m^2)
SM	Short-fibre medium	Hardwood	0.53	209
SC	Short-fibre coarse	Hardwood	0.74	242
MX	Mixed	Mixed furnish	0.89 (for hardwood)	250 (for hardwood)
			0.53 (for softwood)	150 (for softwood)
LF	Long-fibre fine	Softwood	0.77	190
LM	Long-fibre medium	Softwood	1.09	233

The width of the bars and the width of the grooves both increase in a systematic way from the SM-type down the column to the LM-type. This has the effect of reducing cutting edge length and surface contact area, which change the values of both SEL and SSL. Generally, both parameters are in the normal range for hardwood but low for softwood, because the mill only treats this type of pulp very lightly.

The mill trials were designed to give direct comparisons of performance between the softwood fillings, by switching between the normal and spare softwood refiners on the run. The LM design was therefore compared first with the LF and later with the compromise MX filling. Similarly for hardwood, the SM was compared with the SC and MX fillings. Operation of the pulper was standardised, refiners were run at the same kWh/tonne level with no re-circulation, and conditions down the machine were carefully monitored.

Case History 3 Continued

The most significant indication of change came from test results on stock samples taken immediately after refining (see Table 6).

Table 6 Fibre development in softwoods

	Tensile strength (Nm/g)	Burst index index (kPa m^2/g)	Tear factor factor (mN m^2/g)	Schopper (°SR)	Energy difference (kWh/tonne)
LM to LF	-13.3	-0.87	+2.3	-3.5	+18
LM to MX	-15.6	-1.04	+2.0	-5	+22

It is clear from these figures that, in order of development, the LM fillings are more efficient than the LF fillings which are more efficient than the MX fillings. In other words, for softwoods the widest bars and grooves are best and the narrowest worst at developing the fibre. This is in keeping with best performance relating to higher SEL and SSL values. **In this case it is estimated that the change from MX (0.53 J/m) to LM (1.09 J/m) fillings could save 22 kWh/tonne or 66p/tonne at 3p/kWh.**

The test results for similar trials carried out on hardwood after refining are shown in Table 7.

Table 7 Fibre development in hardwoods

	Tensile strength (Nm/g)	Burst index index (kPa m^2/g)	Tear factor factor (mN m^2/g)	Schopper (°SR)	Energy difference (kWh/tonne)
SM to SC	-1.5	-0.17	-0.8	0	+4
SM to MX	-2.1	-0.36	-1.4	-1	+7

Here again the effect relates in sequence to the different bar and groove widths, with the narrowest being best and widest worst at developing the fibre. In this case for hardwood, low SEL and SSL values are best. The savings here are much smaller as the optimum SEL of 0.2 J/m for hardwood has not been reached, but **is still significant and relates to a saving of 21p/tonne or £10,000 for a medium-size (50,000 tonne/year) mill.**

3. REFINER INSTALLATION ARRANGEMENTS

The major considerations when installing or upgrading a refiner system are: the fibres used; the properties to be imparted; future product needs; and raw materials. A system should always be designed with consideration for future product development. There are many systems which were designed primarily for softwood furnish that are now unable to cope with a predominantly short fibre furnish.

The key decisions when selecting a refiner system are:

- the refining action necessary (number and intensity of impacts) - see Section 2.1.2;
- the type of refiner able to achieve the above efficiently and correctly - see Section 2.3;
- the refiner installation, i.e. mixed or separate refining, series or parallel operation and continuous or batch mode of operation - see this Section;
- system control - see Section 5.

3.1 Mixed and Separate Refining

The methods of refining a mixture of softwood and hardwood may be described as follows:

- mixed refining - all components treated equally in the same refiners;
- split mixed refining - where there are two or more refiners in-line, the first refiner set up to treat the softwood component correctly and the second and subsequent refiners set up to treat the hardwood component;
- sequential refining - where the softwood component is refined separately, the hardwood then added and the whole mixture refined to desired specification;
- separate refining - where each component is refined individually to its best advantage using optimum treatment.

Case History 4 Mixed versus Separate Refining

The refining system at Inveresk Caldwells Mill on PM5 machine was set up as a parallel/series system using three double disc refiners. (The problems associated with this type of layout are discussed in Section 4.) The refining system was completed by two wide angle conical refiners running in parallel in the machine refiner position, to provide a final control of stock properties. A schematic of the system is shown in Fig 14.

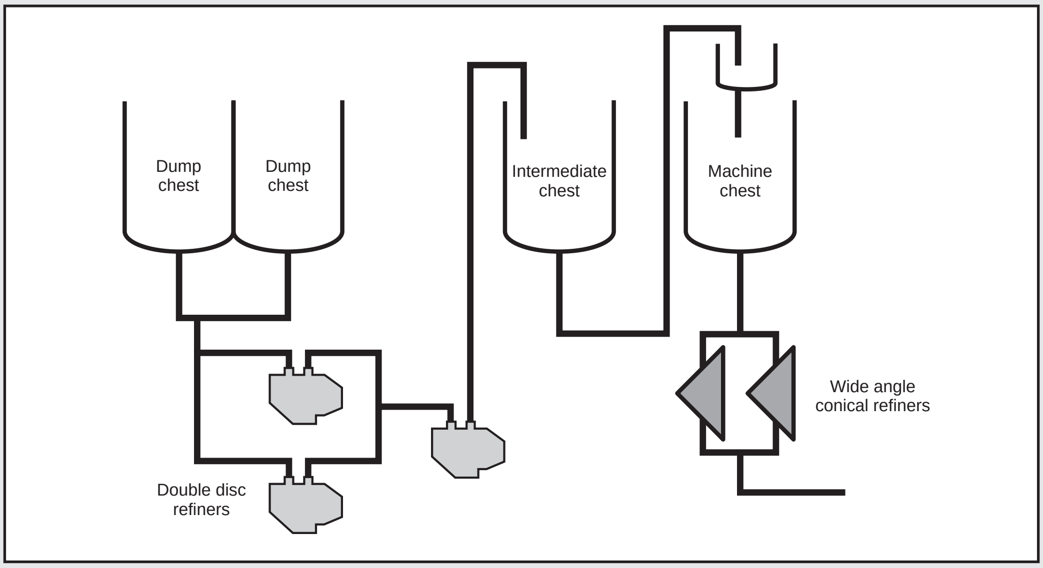

Fig 14 Mixed refining system

Case History 4 Continued

With this system, normal practice was to use three double disc refiners and either or both of the conical refiners. For two of the main products, parameters for the system averaged over nine months were as follows:

Product A	Average throughput 7.8 tonne/h Gross energy 175 kWh/tonne
Product B	Average throughput 7.7 tonne/h Gross energy 179 kWh/tonne

There were some disadvantages in the system that could be solved in various ways, the selected method being separate refining of the softwood and hardwood components. No new refiners were necessary, but extensive pipework changes were involved. The new system layout is as follows:

- Softwood refining utilises a double disc refiner fitted with fillings to produce the correct flow and intensity. Two wide angle conical refiners are used as back-up, fitted to the softwood line as this type of refiner is more suitable for longer, tough fibres. All refiners are in series;
- Hardwood refining utilises two double disc refiners installed in series, fitted with fine barred fillings to give as low an intensity refining as practicable.

A schematic of the system is given in Fig 15.

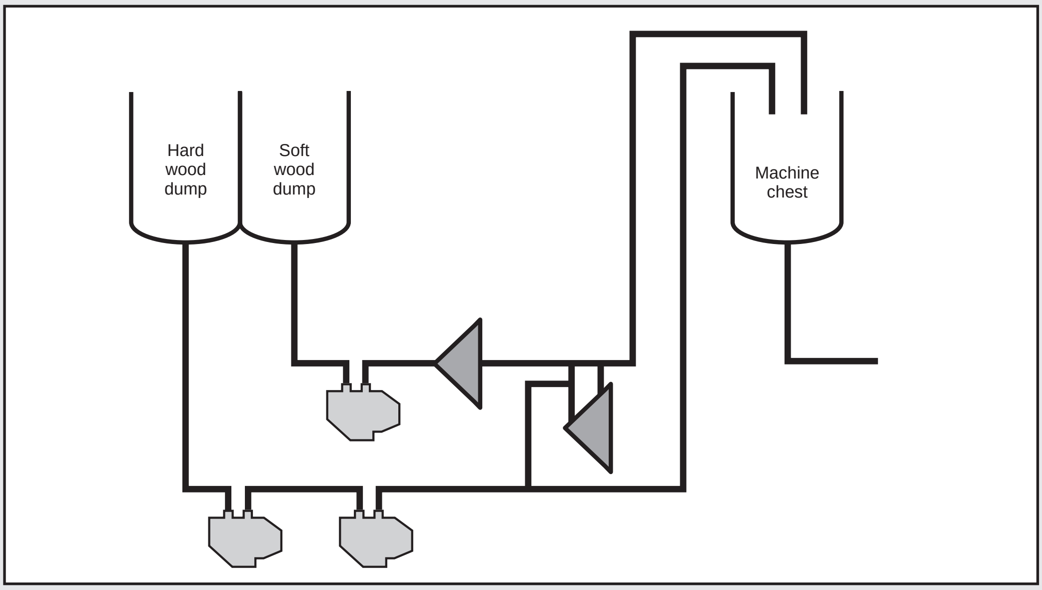

Fig 15 Separate component refining system

In operation, one of the conical refiners proved to be unnecessary and the machine normally operates with three disc refiners, with occasional need for one conical refiner on the softwood line.

Case History 4 Continued

On the same two products the parameters for the system, again averaged over a nine month period after the change, are:

Product A	Average throughput 8.5 tonne/h Gross energy 132 kWh/tonne
Product B	Average throughput 8.2 tonne/h Gross energy 131 kWh/tonne

The figures show that the change from mixed to separate refining has increased throughput by 7% - 9% and decreased the average gross energy use by 26% (45 kWh/tonne).

At a cost of 3p/kWh this represents cost savings of £1.35/tonne, or £67,500/year for a medium-size (50,000 tonne/year) mill.

In this case, as the existing refiners were used, the payback was six months. If replacing a system because of obsolescence or wear, payback would be approximately four years.

Case History 5 Mixed versus Separate Refining

The benefit of separate refining was confirmed in a direct comparison made on the Inveresk Carrongrove board machine. Normal operation at the mill uses the pulper to slush either a hardwood blend or softwood, dropping each to a separate dump chest. These two pulps feed the appropriate refiner with forward flow regulated by automatic ratio control that includes a separate broke line.

While the machine was running normally, a number of batches were made up in the pulper with the two pulps fed in together in approximately the usual ratio. All other conditions, in particular broke and chemical addition, were kept constant. The resulting stock was then passed through a spare refiner that had been fitted with a compromise set of bar fillings; the load on the refiner was set to give the same SEC as overall on the separate refiners

A full series of tests and measurements were taken and final board quality was carefully monitored to compare with normal running.

After switching to the blended pulp it quickly became apparent that conditions were changing and quality was deteriorating to the point where there was danger of rejection. So after taking samples at various positions the trial was aborted.

The data that best sums up the effect of blending in the pulper is for samples from the head-box feeding stock to the machine (see Table 8).

Case History 5 Continued

Table 8 Comparison of separate and blended pulping

	Headbox samples	
	Separate pulping	**Blended pulping**
Tensile index (Nm/g)	41.4	36.3
Burst index (kPa m^2/g)	2.42	2.13
Tear index (mN m^2/g)	13.7	12.3
Schopper (°SR)	21.0	18.8

Table 8 shows that a much lower fibre development was obtained for the same energy input with blended pulping, with tensile, burst and tear index and Schopper Reigler all decreasing. **Separate refining is more efficient, primarily because it allows bar patterns to be selected that are best suited to the fibre being refined.**

Separate refining can be more energy efficient than mixed refining

3.2 Series or Parallel Operation

In systems containing more than one refiner in-line, there are a number of types of installation, i.e. series, parallel and combination systems (Fig 16).

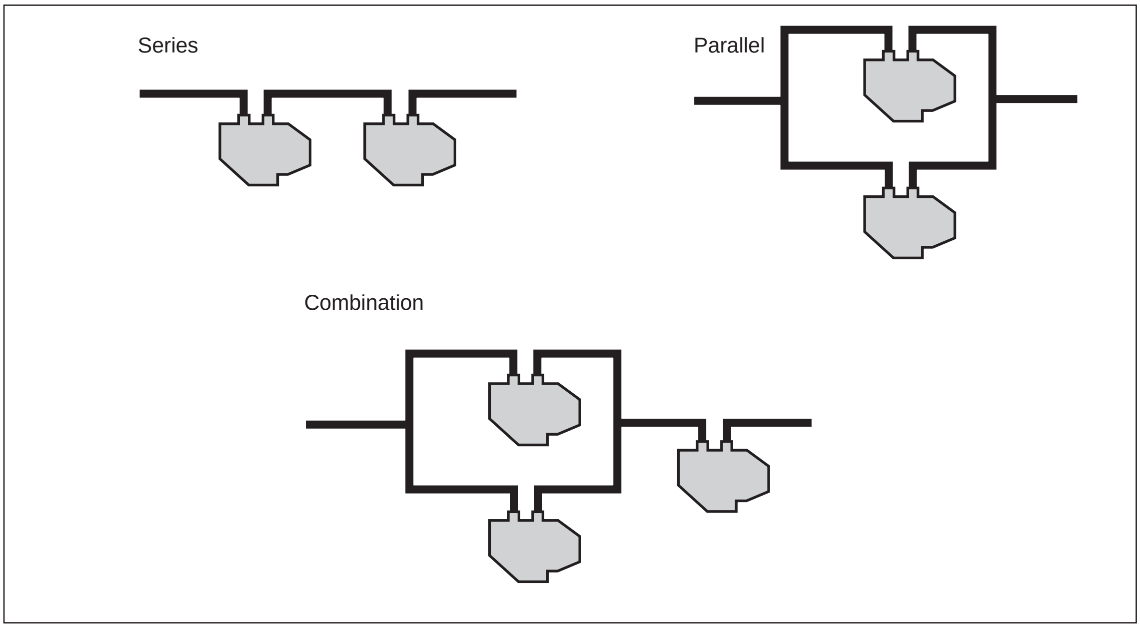

Fig 16 Series, parallel operation and a combination of the two

The use of the combination system arose from a belief that only two refiners could be operated in series, although there are now a number of systems where three refiners are used in series. Where flexibility of operation required the use of more than two refiners in-line, either parallel or combination installations were used. Combination systems are certainly flexible in that series ***or*** parallel operations can be used if only two refiners are needed.

The major disadvantage of systems involving parallel operation is the control of flow through the refiners. Another disadvantage is the use of different powers on refiners because of differences in flow. Even where pipes are equal size, it is difficult to obtain equal flows through refiners in parallel.

Case History 6 Parallel/Series Combined Operation

The refining system on PM5 machine at Inveresk Caldwells Mill had a parallel/series operation with double disc refiners, to treat a mixed furnish. The three refiners were equally-sized with the same fillings. A study of this system revealed that the flows through the parallel refiners (Refiners 1 and 2) could differ by up to 32%. All fillings were sized for full flow and so the fillings in the parallel refiners were undersized. A system schematic is shown in Fig 17.

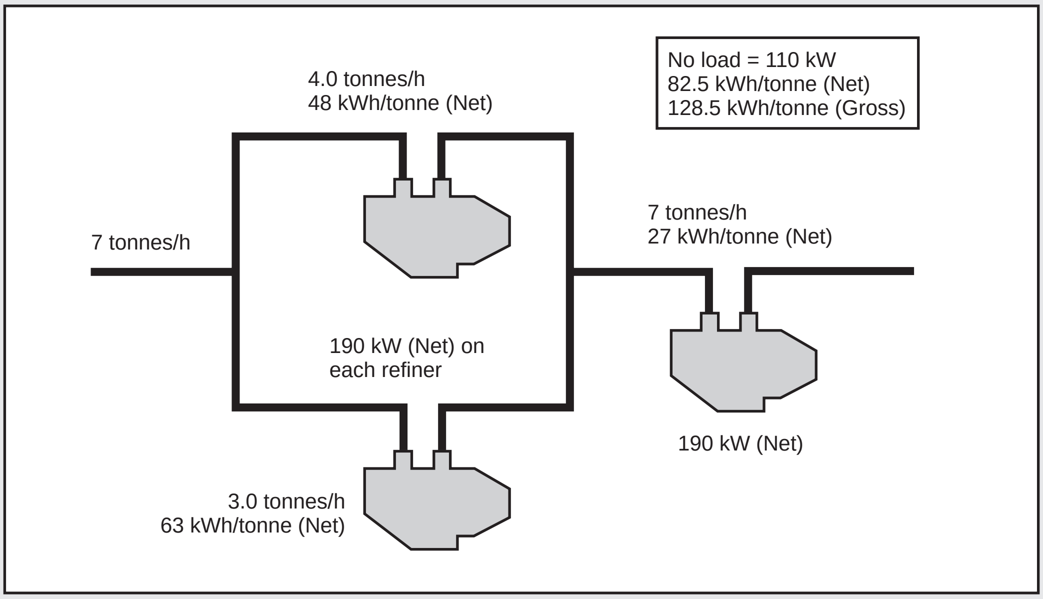

Fig 17 Series/parallel combination

The system as shown has the following characteristics:

- unequal energy input for each refiner leading to heterogeneous action and product quality variation;
- a refining intensity which is too low for a softwood/hardwood mixture;
- uneven flow through the refiners in parallel.

The suggested modification was to have all three refiners in series but, in practice, in series operation the system proved satisfactory with only two refiners operating at higher load, as shown in Fig 18.

Case History 6 Continued

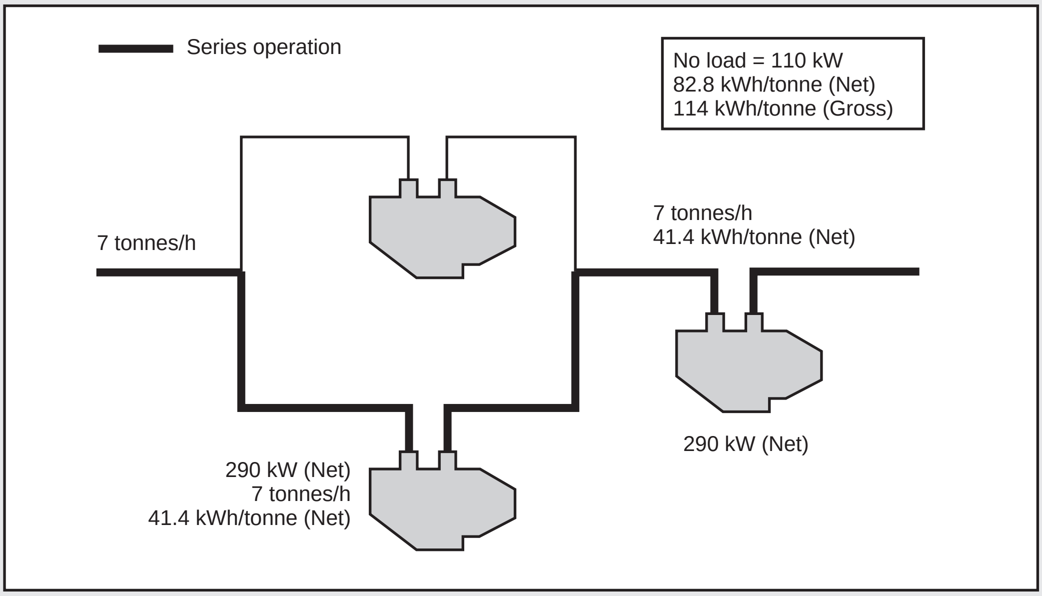

Fig 18 Using two refiners in series

Using two refiners gives a more ideal refining intensity and energy savings of 15 kWh/tonne. **This modest saving represents a cost reduction of £0.45/tonne at a cost of 3p/kWh, or £25,000/year for a medium-size (50,000 tonnes/year) mill.** There is also a spare refiner should the one of the others need maintenance. The more homogeneous refining may improve the property balance, resulting in greater energy savings. Actual savings are not available as the system was changed from parallel to series refining at the same time as the change from mixed to separate refining (see Case History 4).

4. OPERATIONAL PARAMETERS

This Section highlights the essential parameters involved in the refining process which affect energy use. The following parameters are of most importance when refining or considering a new refiner installation:

- no load power;
- throughput and residence time;
- refiner power as specific edge load or severity of impact;
- refiner energy, either net when quantifying action on fibres, or gross when considering cost or design;
- refiner filling (also known as tackle, discs, plugs and shells);
- rotation speed.

4.1 No Load Power

The no load power has a major impact on refiner efficiency and, consequently, on energy use in stock treatment. This operational parameter varies according to the condition of the refiner, stock throughput and the condition of fillings.

4.1.1 *Refiner Condition*

In many installations with older Jordan refiners, backing off refiners does not change the power reading at all. As no loads are rarely measured this is not observed and the refiner is seen as ‘not doing its job’. **Refurbishing refiners in these situations can result in substantial energy savings** (see Case History 7).

4.1.2 *Stock Throughput with Double Disc Refiners*

Refiner fillings for a double disc refiner are designed for a specific stock throughput, normally specified as volumetric flow in litres/minute. The range of flow capacity, which is determined by the bar angle, can be between 50% and 110% of that specified. The central rotor is allowed to float to maintain an equal gap between discs in each zone.

With incorrect flow, however, the equalisation of gap is disrupted. This is particularly obvious in double disc refiners in monoflo (series) operation, but also occurs in duoflo mode. Using the notation in Fig 10, when flow is below the capacity of the plates, numbers 1 and 2 discs are pulled together to behave as a single disc refiner with high no load due to friction between the plates. If flow is too high, then numbers 3 and 4 discs are pulled together with the same result. The occurrence is obvious by the noise at no load but, as many refiner systems are located in remote places, it may not be noticed. Where refiners are in good condition the problem is self-rectifying but where bearings are worn and sliding mechanisms rusted together, the plates may stay together affecting subsequent production. **This situation can be avoided by measuring no load at frequent intervals, e.g. once per shift, and by regularly servicing refiners. Where significant changes in flow have occurred, consult the manufacturer to establish whether changes in filling pattern are required.**

Case History 7 No Load Reduction by Refiner Refurbishment and Filling Design

As part of a refiner assessment at Kimberly Clark Ltd (then Scott) in Barrow, the condition of each refiner was measured. Of most importance were the 26 inch double disc refiners which carry out most of the refining on PM1 and PM2. At the time of the study it was noted that no loads for the two refiners were 195 kW and 210 kW respectively, giving efficiencies of 35% and 30%. Subsequent investigations showed that the sliding assemblies were worn and, in the case of PM2, there was plate contact at no load as indicated by noise. In addition, the plate angles were designed for a higher flow which contributed to the high no loads through plate contact on PM2.

The problem was addressed in two ways:

- at the time of fitting new fine barred plates (Case History 8), the bar angles were changed to cover the range of flow currently in use.
- new quill assemblies and bearings were fitted and the refiners generally refurbished.

After the changes, the no load of both refiners PM1 and PM2 was 158 kW, giving an efficiency of 47%. In terms of energy use, the saving is, on average, 27 kWh/tonne on PM1 and 42 kWh/tonne on PM2. The extra available power enabled machine speed increases. **At a cost of 3p/kWh, this represents a cost saving of £0.90/tonne for PM1 and £1.26/tonne for PM2, or £50,000 to £63,000/year for a medium-size (50,000 tonne/year) mill.**

Proper maintenance and fillings = lower no load = higher refiner efficiency

4.1.3 *Filling Wear*

The no load power of a refiner is dependent on groove depth which affects the hydraulic capacity or pumping action of the refiner. When a filling is very worn the grooves disappear and pumping ability is lost. The resulting low no load gives an appearance of efficiency, but is actually a result of the refiner no longer operating effectively.

Case History 8 Effect of Filling Wear

Studies on a refiner system in a fine paper mill using two refiners in series showed that the no load of refiner No. 1 was 57 kW, while the no load of refiner No. 2 was 83 kW.

Assuming the No. 2 refiner to be in bad condition, an inspection was made but the fillings were unworn and operation was satisfactory. The No. 1 refiner was then inspected to identify the reasons for the ‘efficient operation’ and the fillings were found to be completely worn. Under normal operation both refiners were run at 260 kW each, so No. 1 refiner would have had a higher SEL than No. 2 refiner, leading to strength deterioration which would eventually have been rectified by increasing the energy levels. On replacement of the worn fillings the no load of No. 1 refiner was equal to that of No. 2.

Regular no load measurement can identify worn fillings and also worn refiners

4.2 Residence Time/Recirculation

The residence time in a particular refiner is determined by a number of factors, mainly throughput and whether fillings are dammed, preventing flow across the grooves. Dams in fillings are a part of 'refining lore', but there is little evidence to support their efficiency.

Where a refiner is oversized and there is cavitation, the fibre mat between plates will be thin and at times non-existent. Initially the refiners in most systems will be correctly-sized, but problems can occur over the years with production changes and where different grades, or different deckles, are made on one machine. In these cases, the throughput can vary beyond the range of filling and refiner capacity.

Correct fillings can alleviate some of the problems, but a popular solution is to use recirculation loops to maintain a more constant flow through the refiners. This arrangement is also used to control the flow of stock that is fed forward from the refiner to the machine system (usually in conjunction with a main throttling valve), while providing a means of keeping minimum flow and pressure in the refiner within safe operating limits.

With a recirculation loop, stock is returned to the inlet of the pump. As stock flow requirements are changed, the control valve will alter the degree of recirculation to allow flow through the refiner to remain constant. The loop can be pressure-controlled which avoids the possibility of fillings clashing because of a low flow condition. An example recirculation system is shown in Fig 19. One disadvantage of this system, however, is that as demand for refined stock varies and the recirculation flow alters appropriately, so the treatment of stock varies. More importantly, recirculation has been shown, at least for conical refiners, to be detrimental to energy efficiency.

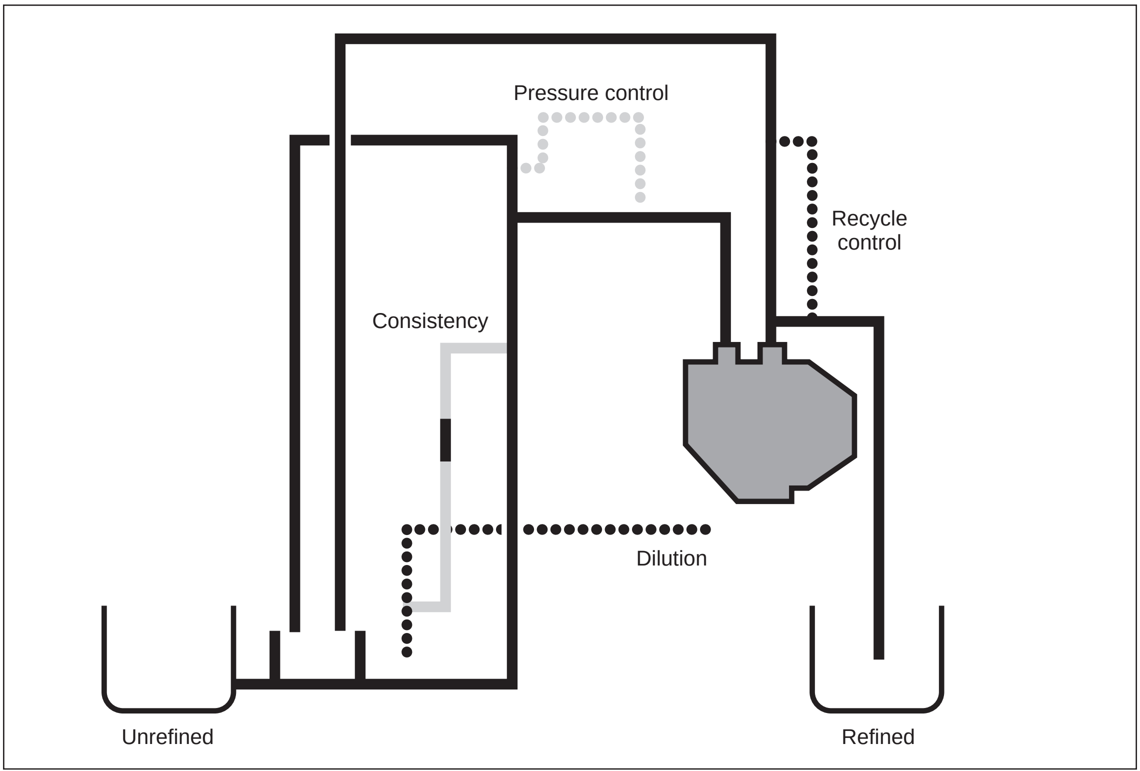

Fig 19 An example of a recirculation loop

Case History 9 Effect of Re-circulation

In trials at the Inveresk Carrongrove board mill, the recirculation factor round a softwood refiner was deliberately changed while other conditions, notably the operation of the pulper and SEC in the refiner, were kept constant. Recirculation factor is defined as the ratio between flow round the refiner and total flow through the refiner so, for example, a ratio of 0.5 means that the flow in the recirculation pipe is half that through the refiner, the other half passing forward to the machine. Tests were carried out for three different forward flows.

While the results were, to an extent, scattered, the lines of best fit for each of the three flows clearly indicated that fibre development was lower as recirculation increased, particularly at the lowest flow rate. For example, tensile results on hand sheets made from samples of the stock fed forward from the refiner showed a drop for high forward flow from 55 to 50 Nm/g as recirculation was increased from zero to 0.7, with an even greater drop to 45 Nm/g for the lowest flow forward. Similar results were obtained for burst and tear data. A trial altering re-circulation round a hardwood refiner gave a similar pattern, although the results were more erratic.

Conclusions from the work were that higher recirculation at a given SEC gave poorer strength development, i.e. passing fibre more than once through a refiner by recirculation was less efficient.

Similar results have been found for a conical refiner in other work on a pilot-scale unit, but they differ from those found in work done by Beloit[1] on a disc refiner where, particularly for hardwood, re-circulation was found to have beneficial effects on strength development. Caution is therefore needed in interpreting these results.

4.3 Consistency

The major effect of changes in consistency is the change in throughput. In most cases where mills have consistency control the variation is small. Energy control is preferable to power control because changes in consistency (and flow) are allowed for and corrected.

4.3.1 *Low Consistency Refining (LCR)*

The effect of consistency is greater for a hardwood than for a softwood pulp, because of the greater strength of the softwood fibre. Practical experience shows that over the range of 4 - 6%, softwood refining consistency should be toward 4% while hardwood should have a consistency toward 6%.

4.3.2 *High Consistency Refining (HCR)*

The method of refining devised by Bauer at 35% - 40% consistency has been in operation for a number of years. The benefits claimed for HCR are:

- preservation of fibre length
- improved wet and dry strength properties
- opacity can be lower for HCR than LCR

Initially this method was thought to be energy intensive, but later experiments showed a decrease in specific energy as consistency was increased. There has, however, been little development of the concept.

[1] Jorg Rihs, William Josephson, Beloit ‘Refining systems with flow recirculation’, Fourth International Refining Conference, Fiuggi, Italy, 18-20 March 1997, Paper 7, page 115.

4.4 Refiner Filling Configuration

Refiner fillings can be used to improve energy use and there are a number of parameters involved.

4.4.1 *Bar Dimensions*

The power applied to a refiner determines the type of fibre treatment. As the power applied also determines the energy applied, it is clear that one cannot be changed without the other. This can lead to problems where, because of changes in flow and/or consistency, more refiner energy is required to achieve a stock property, such as wetness, or paper properties, such as porosity. The problem is more commonly seen where machine output has increased or furnish properties have changed over a period of time without any changes being made to refiners.

The problems can be particularly acute where a system has only one refiner, as shown in the following example.

Example Effect of Power Changes

Fig 20 shows three refining curves of breaking length against net energy input at different SEL. Assume that normal refining is at Point A (120 kWh/tonne). If there is an increase in throughput, then power will have to be increased to maintain net energy, either as a function of energy control or because of a change in final properties which cause the paper to be out of specification.

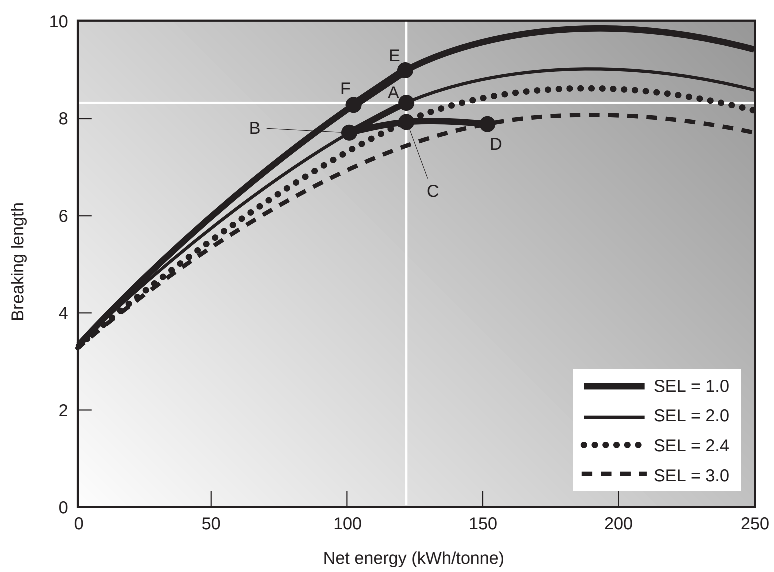

Fig 20 Effect of power changes

The horizontal line on the graph shows the minimum target value for breaking length. Normal running for this particular refiner is at Point A (120 kWh/tonne), with the applied power in kW giving an SEL value of 2.0. A (small) change in throughput as a result of other changes on the paper machine will have little effect on the net power in kW and so the SEL will remain constant. It will, however, change the SEC.

For a fibre flow increase of 20%, the SEC will fall to 100 kWh/tonne at the same power and SEL (2.0), such that the refiner will operate at point B on the graph. This is not an acceptable value for breaking length. Normally the operator would decrease the gap to increase the power by 20%, moving back to 120 kWh/tonne on the x-axis. However, this

Example Effect of Power Changes (continued)

also increases the SEL by 20%, so that operation does not return to point A on the graph, but moves to point C, corresponding to SEL of 2.4. At point C the breaking length is still not acceptable. Even if the gap (motor allowing) is wound in to increase the applied power by 50% to 150 kWh/tonne, the SEL increases to 3.0, the refiner operates at point D and the breaking length is still too low. It is not possible to reach the required value of breaking length by increasing applied power.

One way to return to point A would be to increase the applied power by 20% while decreasing the rotation speed. This keeps the SEL constant at 2.0 by reducing the cutting length (Ls) of the refiner tackle by 16.7%.

However, motor control is usually such that this is not possible. The only solution, therefore, is to change the refiner fillings. A finer bar pattern, giving more bars for a given area and doubling the cutting edge length, would operate at point E under normal conditions (with an SEL of 1.0). This has a higher than minimum value of breaking length for the same SEC of 120 kWh/tonne. A 20% increase in mass flow now changes the SEC to 100 kWh/tonne at point F, where the breaking length is now the acceptable minimum value. Refiner fillings should be chosen so that the required properties are developed at the worst possible case encountered in normal operation, not the usual operating conditions.

In this new situation, if the gap is widened and the power backed-off at normal fibre flow, the breaking length should increase further at a much lower kWh/tonne, as the refiner performance shifts to a curve of even lower SEL. In practice, there is a limit to how far this can go, because of the limitations of the refiner in terms of flow and the effect on the other required paper properties as power is reduced. (This also applies to the selection of new tackle.) In addition, as the motor power changes from its optimum value, the overall energy efficiency (allowing for motor losses) could decrease significantly. Allowing for all these constraints, it is usually possible to select a filling with the required performance.

Correct fillings = energy saving and/or property improvement

Case History 10 Power/Energy Relation

The refiner system on PM2 at Kimberly Clark Ltd (then Scott) in Barrow consists of a single double disc refiner on the virgin fibre line, with a machine refiner later in the system.

Trials were carried out to assess the improvement in product properties against increased power. The results showed that after a certain point gains in tensile were minimal. The refiner fillings were changed to a finer pattern to give a more balanced treatment of the mixed softwood/hardwood furnish. Subsequent tests showed that the tensile had improved by almost 40% for the same power input.

In this case the increase in tensile was the objective and was gained without an energy penalty. In other situations where tensile is not a problem, an equivalent tensile could be achieved at an energy saving of 30 kWh/tonne (i.e. going from current refining at point A to equivalent tensile at point F on Fig 20). As machined discs were in use, the change in fillings involved a recutting cost only, giving a payback period of just six months. **At an approximate cost of 3p/kWh, the cost saving was £0.90/tonne, equivalent to £45,000/year for a medium-size (50,000 tonne/year) mill.**

4.4.2 *Disc Diameter*

Until relatively recently fine paper furnishes contained more long fibre than short. Typical ratios were 70:30 or 60:40 softwood to hardwood. Over the last 20 years this trend has reversed and furnishes can now contain up to 90% hardwood. This reversal in papermaking practice can cause flow problems.

Example Effect of Furnish Changes

A mill was originally designed to refine separately a furnish of 60% softwood and 40% hardwood at a throughput of 3 tonne/h and a consistency of 4%. Total volumetric flow was 1,250 litres/min, comprising 750 litres/min through the softwood refiner and 500 litres/min through the hardwood refiner. 24 inch double disc refiners with 410 to 900 litres/min capacity fillings were used to treat these flows.

In time, the furnish changed to 20% softwood and 80% hardwood with a machine increase (quite common) of 10%. Flow through the refiners increased to 3.3 tonne/h or 1,376 litres/min, with 274 litres/min flow through the softwood refiners and 1,102 litres/min through the hardwood refiners. At these rates, the softwood flow was well below plate capacity and the hardwood flow well over.

For the hardwood refiners, angles can be changed to cope with the increased flow (see Section 5). The softwood refiners were close to the minimum capacity of a 24 inch double disc refiner. The problem can be solved by reducing the disc diameter to 20 inch, either by fitting 20 inch discs with blanking plates or by removing the bars from the existing 24 inch filling to a 20 inch radius.

The 24 inch and 20 inch fillings were tested in a UK mill, and the results are shown in Table 9.

Table 9 Relation between filling diameter and no load

	24 inch filling	**20 inch filling**
Total power (kW)	350	350
No load power (kW)	95	57
Efficiency (%)	73	84

At a throughput of 1.1 tonne/h, the energy saving is 34.5 kWh/tonne.

Reduced filling diameter = reduced no load power = reduced energy

4.5 Rotor/Stator Crossing Angle

The cutting angle of a filling determines the propensity to cut or fibrillate: low crossing angles promote cutting, high crossing angles promote fibrillation. This is because when the cutting angle is changed, the number of bars of the same width that can fit into a particular plate also changes. Table 10 shows the effect that changes in angle will have on a filling of equal groove and bar width (Beloit fillings).

Table 10 Effect of changing bar angle for 34 inch Double disc 2-2-4 (Imperial) fillings

Angle	**Cutting edge length (km/s)**	**SEL @ 300 kW net (J/m)**
5°	102	2.9
10°	125	2.4
15°	165	1.8

The change in cutting angle alters the specific edge load for a given power, although the type of filling (2-2-4) is apparently unchanged. Cutting angle also determines the flow characteristics of a filling. The capacity of a refiner may be changed by changing the angle.

4.6 Filling Weight (Double Disc Refiner)

The way in which the two zones of a double disc refiner can be installed as monoflo (series) or duoflo (parallel) operation is described in Section 2.3.3.

A specific way of converting from monoflo to duoflo is to use the Pilao 'Tri-Disc' conversion, which is claimed to reduce energy consumption by producing more even treatment and lower no load (Fig 21).

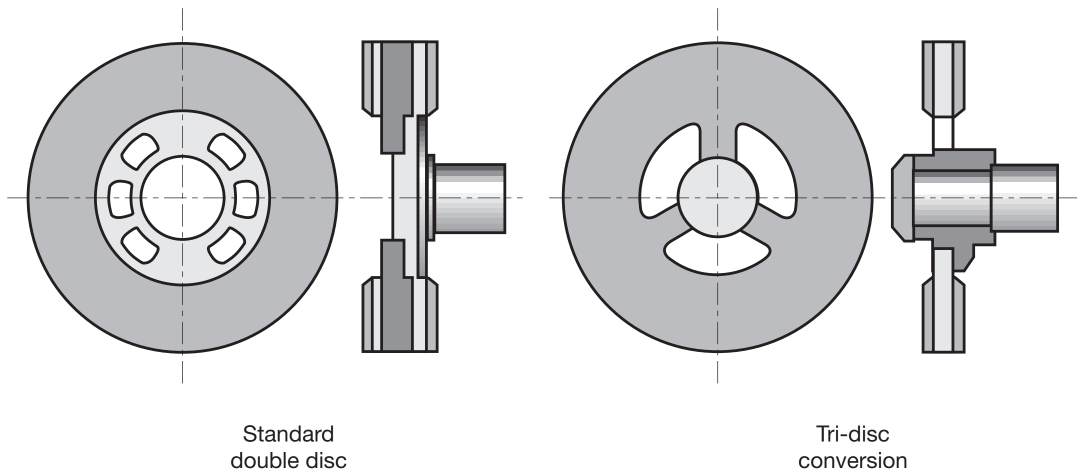

Fig 21 Comparison of standard double disc and Tri-Disc conversion

It is claimed the Tri-Disc results in energy savings of up to 25% due to the open area and weight of rotor, which reduces no load power. The reduced weight (from reduced thickness) of the Tri-Disc filling (Table 11) comes from the monobloc design of the rotor element.

Table 11 Relative weight of the rotors in standard and Tri-Disc systems

Disc diameter (inch)	Original rotor (kg)	Tri-disc rotor (kg)
20	131	58
24	160	90
26	262	125
30	305	177
34	516	216
38	600	300
42	1,116	484
46	1,200	525
54	1,500	630

4.7 Rotation Speed

The rotation speed of a refiner affects no load and refining intensity. In most cases, motors have fixed speeds appropriate to the size of refiner: refiner manufacturers recommend speeds. There is interaction between rotation speed, allowable applied power and no load. Some refiners are fitted with variable speed motors for enhanced operational flexibility.

As the rotation speed of a refiner is increased, the allowable applied power and no load power also increase, and therefore the amount of effective refining power is not increased by equivalent amounts. This effect is demonstrated in the following example.

Example Effect of rotation speed

A conical refiner had two types of filling available, one relatively fine barred (LF), the other coarser (LC) for a cutting action. Speed could be varied from 750 to 1,200 rpm, with maximum power of 51 kW at 750 rpm and 90 kW at 1,200 rpm. Table 12 shows the effect of changes in rotation speed on intensity and no load for both fillings.

Table 12 Relationship between rotation speed, no load and intensity

Filling	Speed (rpm)	CEL (km/s)	Total power allowed at this speed (kW)	No load (kW)	Gross energy (kWh/tonne)	Net energy (kWh/tonne)	SEL (J/m)
LF1	750	22.5	51	11	51	40	1.78
LF2	1,000	30	70	20	70	50	1.67
LF3	1,200	36	90	33	90	60	1.67
LC1	750	13.8	51	11	51	40	2.9
LC2	1,000	18.3	70	20	70	50	2.73
LC3	1,200	22.0	90	33	90	60	2.72

where: LF filling = 1.80 km/rev
LC filling = 1.10 km/rev
Assuming a 1 tonne/h throughput with a 90 kW motor

Example Effect of rotation speed (continued)

An increase in rotation speed will increase the allowable motor power. However, the no load power is also increased at higher motor speeds, so refiner intensities are not as expected. Table 12 shows that, for a given filling, changes in refining intensity as defined by SEL are very small despite significant increases in available energy. Although more energy can be applied to stock at higher motor speeds, efficiency decreases from 79% to 65% as motor speed increases from 750 rpm to 1,200 rpm.

Increased rotation speed is useful for flexibility but not for energy saving

5. REFINER CONTROL

In many UK mills, except where the machine or refining system is fairly new, the operation and control of refining is more manual than automatic. This can lead to problems for a number of reasons:

- many refiners are remote from the machine and are not under the control of the machineman; this can result in drainage and paper properties being controlled by telephone, which hinders the continual maintenance of set conditions;
- measurement is by ammeter, often at a point well away from the operative's attention;
- the only reference property is wetness or freeness, often measured infrequently;
- because of the remote position, unsatisfactory refining may not be noticed until there have been a number of problems on the paper machine.

Even the very simple step of installing the ammeter where the machineman can easily see it can make a big difference, as will the provision of remote, manual control of refiners on the machine control panel. A refiner can often be changed from manual control (by handwheel on the refiner) to remote operation (using a small motor and chain sprocket on the handwheel, which is operated by buttons situated on the wet end operating panel).

More recently sophisticated systems have become available, which can prove beneficial in controlling refiner operation and reducing energy demand.

Control of refining reduces the variation in use and improves product consistency. Also, where a system is automatically controlled there is less opportunity for 'personal choice', i.e. where the refiners are set up to suit the preference of the person in charge of that shift.

Refining is controlled by a number of operating parameters (Fig 22). In mills with automatic controls, power and energy are the parameters most commonly controlled. New methods of operational control utilise drainage rate or stock freeness, measurements linked to energy controllers.

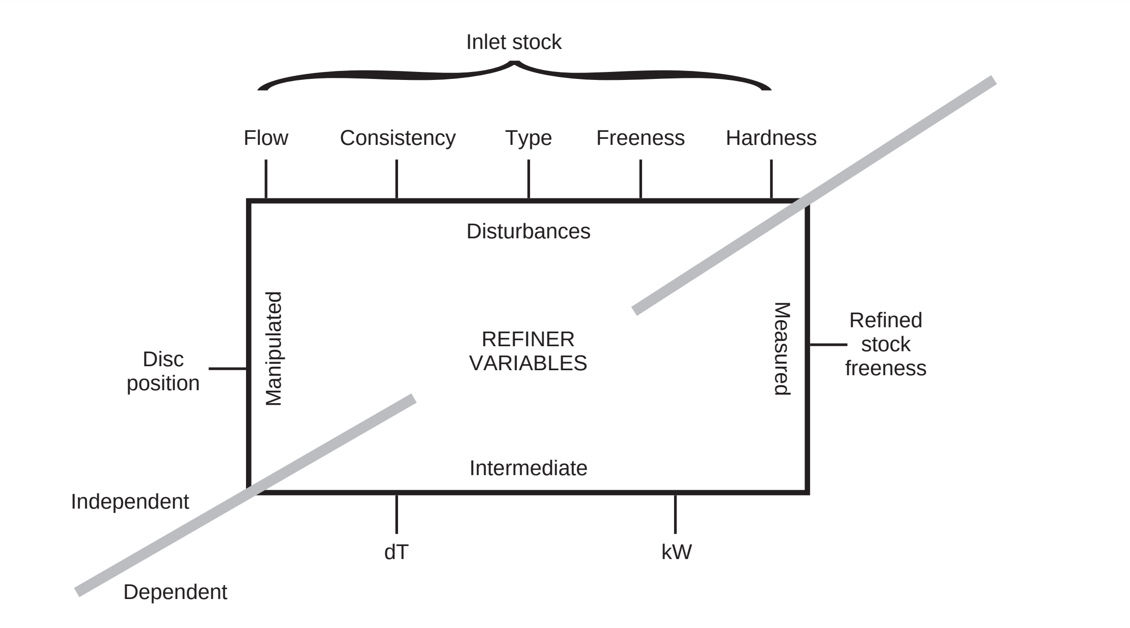

Fig 22 Refiner variables (Source: Tappi, Vol 53, No 5, May 1970)

5.1 Control of Power and Energy

5.1.1 *Control of Power*

Constant power control is the simplest system, maintaining refiner power at a given set point. The system is inexpensive to install and responds quickly, but it is not responsive to process or furnish changes as, when consistency or flow vary, the refiner set point is maintained and specific energy changes cause the stock to be over- or under-refined (Fig 23).

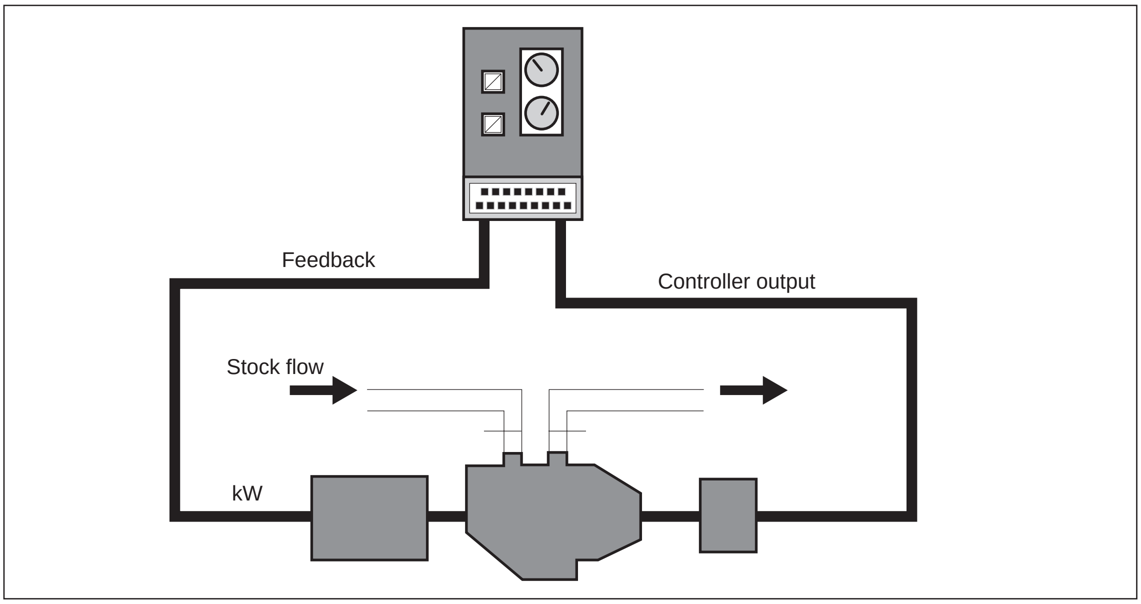

Fig 23 Power control

5.1.2 *Specific Energy Control*

Probably the most widely used system for controlling refiners is specific energy control. While relatively complex, the system provides reliable refiner control. Three process signals (consistency, power and flow) are combined to calculate specific energy. Once a mill has power control, the step to energy control is simple as inputs for consistency and flow usually exist. The controller compares the calculated value with the set point and then adjusts power to maintain constant energy.

The advantage of this control system is that response to changes in flow and consistency are made without sacrificing the response time of power control.

The main disadvantage is that as power fluctuates so does SEL, and therefore large changes in flow or consistency could produce very different fibre characteristics. Nevertheless this method of control is usually accurate and cost-effective.

It is important point to note that an energy control system should measure net as well as gross energy. Although gross energy determines the cost, the net energy determines the fibre treatment and end product quality. **The no load power parameter must be incorporated into calculations and should be updated *at least* once each shift.**

Energy control (Fig 24) is believed to save up to 20% in refining energy by maintaining stock quality to an optimum level.

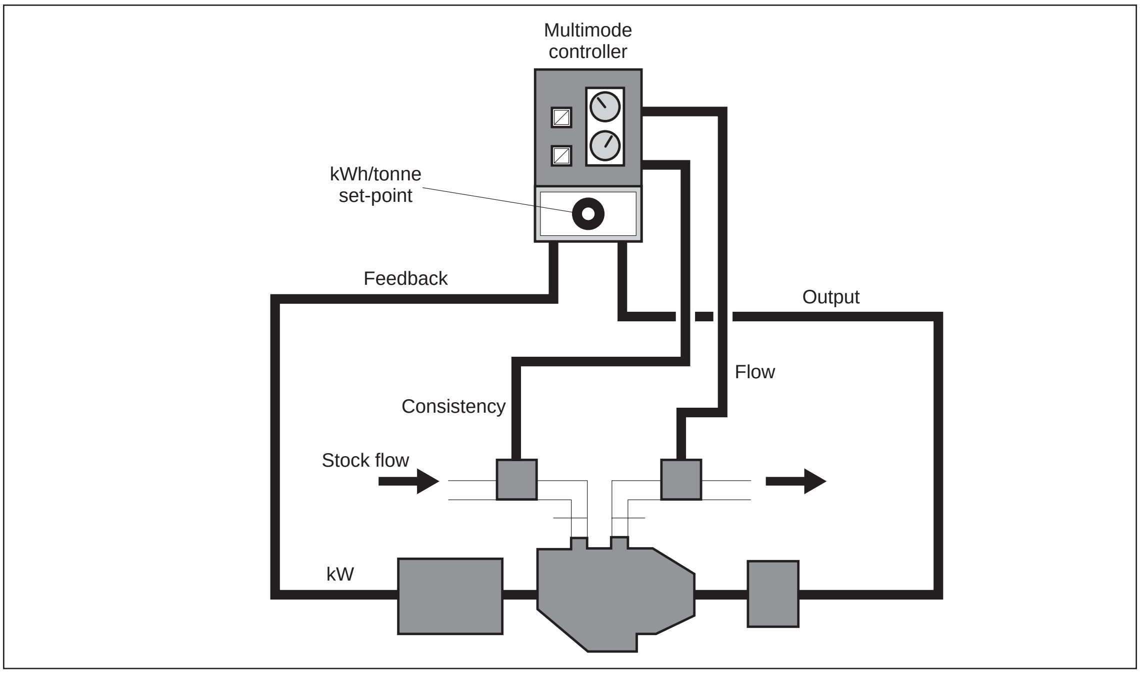

Fig 24 Specific energy control

5.2 Drainage Rate Control

The standard, and in most cases only, stock quality measurements are recorded using laboratory instruments such as Schopper Reigler or Canadian Standard Freeness (CSF). Experience indicates that this aspect of fibre condition, although only a simulation of drainage rate on the wire, relates to end product properties. Current laboratory procedures are well tested but have major drawbacks such as human error, e.g. errors in dilution, temperature readings, sampling etc. Another drawback is 'time' - time taken to process the results and time taken between each sample. In a mill operating a well-organised quality control system, tests are normally carried out frequently, perhaps as often as once every one or two hours, but in most mills it will be only once a shift or even once a day. During any of these intervals, whether an hour, two hours, once a shift or once a day, large quantities of product will have passed through the system untested. An in-line method of measuring freeness or drainage rate can be utilised to produce standard pulp with minimum down time (see Fig 25).

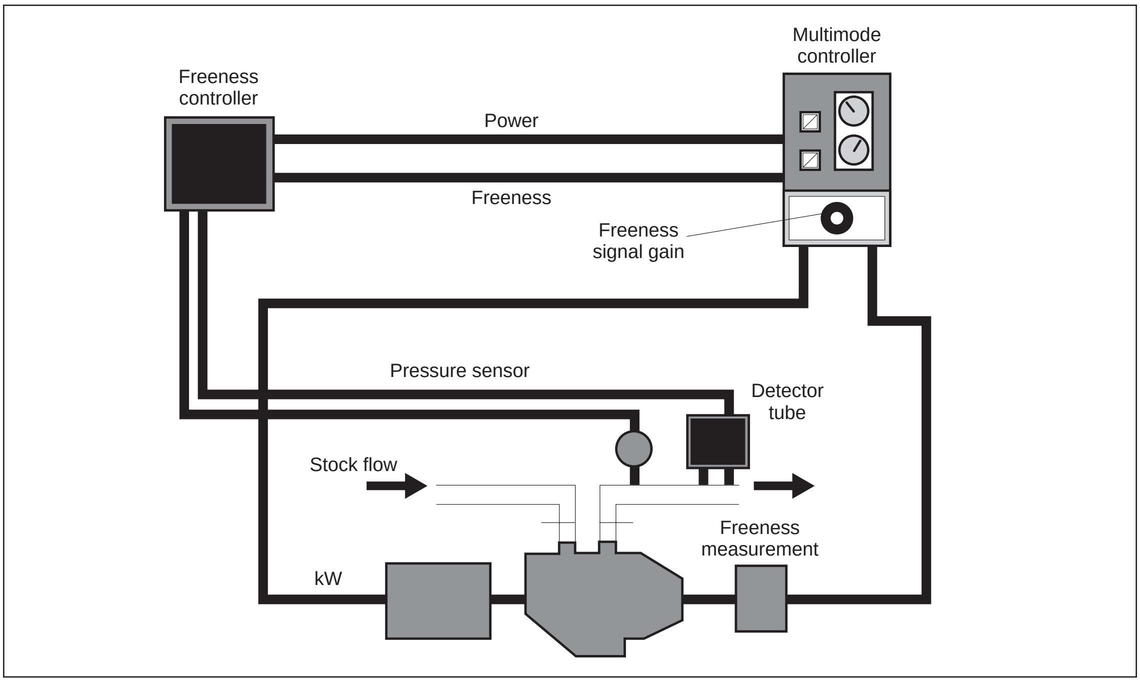

Fig 25 Control by drainage rate

The in-line analyser measures the water permeability of a pad formed from the test stock. The advantages of this control method are:

- no sensitivity to process line factors, such as pressure, flow or temperature;
- relatively insensitive to consistency variations;
- fibre characterising, no measurement during pad formation;
- time response to fines;
- measured values correspond to physical properties, such as specific surface and fibre flexibility.

The measurement is related to drainage during the forming process. The operation of the instrument is complex. Apart from use as a continuous 'wetness' tester, the instrument can be connected to the input of an energy control and be used to control stock quality with minimum energy use.

The continuous Pulp Drainage Analyser gives a measurement that is closely related to the measurement of wetness and freeness (see Fig 26). The instrument has connections for up to four separate sampling devices on the process pipeline and the following parameters for the sampling device can be selected:

- number of partial samples;
- dilution water quality;
- sampling interval;
- mixing and rinsing time.

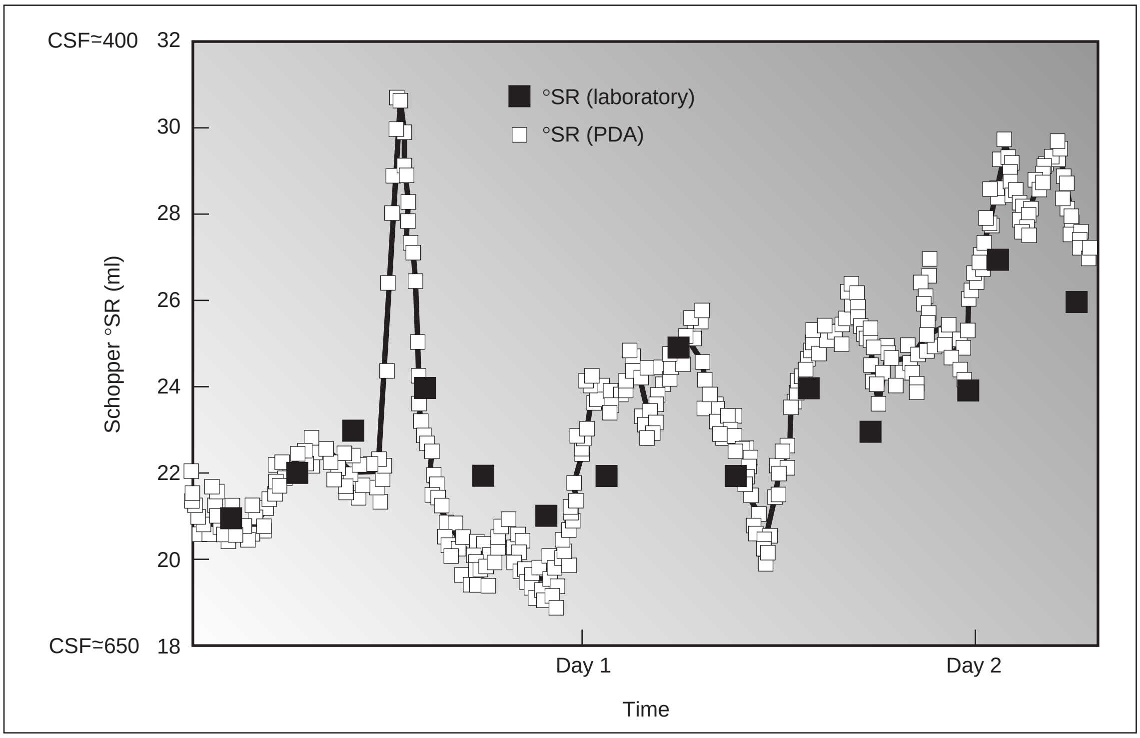

Fig 26 Refining of fluting waste (source: Kajaani literature)

The utilisation of this type of continuous measurement results in tighter control of stock properties and removes the possibility of over-refining and therefore over-use of energy.

6. MAINTENANCE AND REVIEW OF PERFORMANCE

This Section provides guidance on methods of evaluating and maintaining a refining system to attain optimum performance in terms of energy efficiency and product quality. To benefit fully from this Section of the Guide, it is necessary to understand the importance of the refining process and other basics concepts explained in previous Sections of the Guide. The tasks listed in this Section are intended to assist companies carry out an evaluation. An example of how an evaluation helped one company to improve their performance is contained at the end of the Section.

The papermaker must define the fibre modifications required of their process and product in terms of appropriate properties. The next stage is to achieve the desired effect via refining and its control. Correct specifications must exist, while recognising that papermaking is a process of compromise and that optimisation of every property is impossible, e.g. tensile increases with refining, whereas tear usually decreases. Conventionally, the correct balance of cutting and fibrillation has the greatest effect on energy use for a particular product.

6.1 Planning an Evaluation Programme

To achieve performance goals, it is strongly recommended that an evaluation programme is undertaken. This need not be complex and offers the potential to achieve real cost savings and improved refiner performance. It can also contribute to reduced downtime and longer filling lifetime. An evaluation study of a refiner system should progress as follows.

1 Define the objectives, e.g. energy efficient operation, improved product quality or system optimisation.

2 Learn the system configuration. Study system drawings, refiner manuals and, most importantly, talk to the operators.

3 Inspect the condition of the refiner system.

4 Review system operation and check against manufacturer’s recommendations in terms of intensity and energy use.

5 Operate the refiners at different powers, sample before and after each refiner and test the relevant properties. The final step requires careful analysis of data and comparison with supplier claims when the system was commissioned. The best method of evaluating a system is by stock sampling, creation of handsheets and testing of the properties:

- Take samples before and after each refiner: in this way the performance of each refiner in-line can be compared and corrective action taken.
- Make handsheets of the samples using Tappi standard methods.
- Test the handsheets for any properties, but the most useful are tear, tensile, bulk and porosity. If desired, test properties more relevant to product specification.
- Present results in tabular or graphical form. In the latter case, plot properties can be plotted against energy or another property.

Implement changes, ensuring that operators are aware of the reasons for these changes and are properly trained in any new operating techniques. Ensure that new practices are maintained, checking by means of routine inspection.

6.2 Inspection

6.2.1 *External*

The first task is to inspect the appearance of the refiner and its surroundings.

- Check the cleanliness of the refiner - if excessively dirty, this is a first indication of neglect.
- Check for pulp and gland water leakage, a sign of seal and gland packing wear.
- Listen for excess noise from the refiner. Although refining is a noisy process certain abnormalities can be found by careful listening. Intermittent noise can mean the flow through the refiners is too low resulting in cavitation and plate clash. High pitched 'screaming' also indicates insufficient flow, but also may mean the refiner load is higher than the pulp under treatment can stand.
- Feel the refiner casing and bearing housing - excessive heat, i.e. too hot to touch, will mean that there is a problem.
- Check the mechanism for changing plate gap; difficulty in movement denotes wear or damage of the shaft and quill assembly.

6.2.2 *Internal*

Next check the refiner internals.

- Check plate installation sequence with the refiner handbook, if installed in the wrong sequence the capacity and flow capabilities will be incorrect.
- Check for plugging and debris in the grooves of the filling - debris can cause damage and plugging is evidence of incorrect flow.
- If debris is excessive, check the condition of the magnetic trash trap and consider installing a high density cleaner.

6.3 Refiner Fillings

Examine the fillings of a refiner, and record the following information:

- The type of filling construction, i.e. whether segmented, full cast plates or machined.
- The angle (for a double disc refiner). This determines the flow capacity and should be checked by the manufacturer as flows may have altered since the initial installation.
- The material of the refiner filling: stainless steel or Ni-hard are the most common.

Inspect the fillings for wear and damage. In a double disc refiner the pattern of wear is significant. If discs 1 and 2 (closest to the motor) are most worn then flow is too low, whereas if discs 3 and 4 are worn then flow is too high for the angles fitted.

6.4 Refiner Parameters

Record the following motor parameters and check them against manufacturer's recommendations:

- maximum power (amps*, kW or HP);
- rotation speed (is there a gearbox?);
- voltage (ac or dc?);
- power factor (Φ) - a good approximate figure is 0.86 (the mill electrical engineer will have the figure).

*Amps for ac motors can be converted to power using the following equation:

$$\text{Power (kW)} = \text{Amps } \sqrt{3} \times V \times \Phi$$

$$\text{Power (HP)} = (\text{Amps} \times \sqrt{3} \times V \times \Phi)/0.75$$

6.5 Operating Parameters

Check the normal operating parameters of the refiners for each grade and/or fibre type:

- operating power (amps, HP or kW);
- no load power with the refiner completely backed out but with stock flow as normal;
- energy input from power and stock flow (see stock parameters);
- number of refiners (to give total energy).

The no load is a very good indicator of the condition of a refiner and its fillings. High no load denotes bearing wear, damaged shaft or over-tight gland packing; low no load often indicates worn fillings. In either case early action is recommended.

6.6 Stock Parameters

Check and record the stock parameters flow and consistency, from which specific energy demand can be calculated. Consistency is usually controlled but not always measured: it can be checked by sampling the pulper or the refiner dump chest if refiner sampling points are not installed. Flow is usually measured and controlled.

- Check the flow against the capacity of the filling as specified by the manufacture. If incorrect, replace the filling to specification.
- Compare the consistency with the type of fibre being treated, e.g. softwoods require lower consistencies for refining than hardwoods (3.5 - 4.0% as opposed to 4.5 - 5.0%).
- Ensure that the flow, consistency and throughput are consistent with the needs of your product, process and installed equipment.

6.7 Single Refiner versus Multiple Refiner System Evaluation

Where a system has only one refiner, evaluation is easier as samples may be taken from the pulper (before refiner sample) and the dump chest (after refiner sample). Where a system has multiple refiners, sample points are required after each refiner. To evaluate the performance of an individual refiner in a system of two or more, the other refiners will have to be backed off. This will not give problems where capacity is large, but the sequence of operation should be spread over several hours.

As an example, for a system having three refiners in series the method of testing and sampling might be as follows:

- With all refiners operating, take samples before No. 1 and after No. 1, No. 2 and No. 3 refiner.
- Back off No. 2 and No. 3 refiners, measure no load and sample for condition of No. 1 refiner.
- Return to normal operation.
- Back off No. 1 and No. 3 refiners, measure no load and sample for condition of No. 2 refiner.
- Return to normal operation.
- Back off No. 1 and No. 2 refiners, measure no load and sample for condition of No. 3 refiner.
- Return to normal operation.

6.8 Refiner Control

Control is covered in the Section 5. For the purposes of evaluation, study the system for the following:

- If the system is manually controlled, check whether the control is performed at the refiner or from a panel at the wet end. The latter is preferable as it puts control into the hands of the wet end machineman.
- Control of power only offers a low-cost form of control, especially where the product mix is always the same. Control of energy is preferable where there are a number of diverse products, as this form of control can respond to variations in flow and consistency.

Example Performance Evaluation

Table 13 shows a sample data sheet, taken from an actual production machine. There are a number of potential problems in terms of the capacity of the filling for the range of flows, the SEL used and the gross energy.

Table 13 Unmodified refiner system

	Hardwood (max flow)		**Hardwood (min flow)**	
Refiner details				
Make, model and type	34 inch Beloit DD 2000		34 inch Beloit DD 2000	
Mode (eg mono/duoflo)	Monoflo		Monoflo	
Speed (rpm)	506.00		506.00	
No Load (kW)	91.50		91.50	
No Load (HP)	122.00		122.00	
Max power (kW)	375.00		375.00	
Max power (HP)	500.00		500.00	
Filling details				
Filling reference	34EJ 137		34EJ 137	
Configuration	2.2-2.2-5		2.2-2.2-5	
Bar angle (1-2-3-4)*	15		15	
Cutting edge length (km/sec)*	161.41		161.41	
Operating conditions				
Virgin fibre (% and type)				
Softwood content				
Hardwood content	52.00		43.40	
Mechanical pulp				
Mill broke (% and type)	Hardwood % varies with broke %			
Operating power (kW)	262.70	262.70	181.50	181.50
Operating power (HP)	350.27	350.27	242.00	242.00
SEL (J/m)	1.06	1.06	0.56	0.56
Filling capacity (litres/min)	1,360/2992		1,360/2,992	
Volumetric flow (litres/min)	1,716.87	1,716.87	898.23	898.23
Volumetric flow (gallons)	453.00	453.00	237.00	237.00
Throughput (tonnes/h)	4.13	4.13	2.16	2.16
Throughput (US tons/day	108.70	108.70	56.90	56.90
Net energy (kWh/tonne)	41.58	41.58	41.58	41.58
Net energy (HPD/T)	2.10	2.10	2.10	2.10
Gross energy (kWh/tonne)	63.60	63.60	83.94	83.94
Gross energy (HPD/T)	3.22	3.22	4.25	4.25

Example Performance Evaluation (continued)

At maximum flow the refiner fillings fitted are within range, but at minimum flow the fillings are over capacity and will cause premature wear in one zone of the double disc refiner. The SEL is ideal at the power necessary for maximum flow, but is high at minimum flow. Although in both cases net energy is equal, the gross energy is much higher at minimum flow.

Table 14 shows the results of modifying the system. Finer fillings have been used to give optimum SEL for hardwood. At maximum flow two refiners are used and at minimum flow one refiner is used to give the same SEL. Filling angles have been changed and the flow is now within range for both cases. The gross energy is now the same at maximum and minimum flows.

Table 14 Modified refiner system

	Hardwood (max flow)		**Hardwood (min flow)**	
Refiner details				
Make, model and type	34 inch Beloit DD 2000		34 inch Beloit DD 2000	
Mode (eg mono/duoflo)	Monoflo		Monoflo	
Speed (rpm)	506.00		506.00	
No Load (kW)	91.50		91.50	
No Load (HP)	122.00		122.00	
Max power (kW)				
Max power (HP)	500.00		500.00	
Filling details				
Filling reference	34EJ 139/140		34EJ 139/140	
Configuration	1.5-1.5-3.25		1.5-1.5-3.25	
Bar angle (1-2-3-4)*	+5, +15		+5, +15	
Cutting edge length (km/sec)*	357.00		357.00	
Operating conditions				
Virgin fibre (% and type)				
Softwood content				
Hardwood content	52.00		43.40	
Mechanical pulp				
Mill broke (% and type)	Hardwood % varies with broke %			
Operating power (kW)	262.70	262.70	270.74	
Operating power (HP)	350.27	350.27	360.98	
SEL (J/m)	0.48	0.48	0.50	
Filling capacity (litres/min)	802/1,765		802/1,765	
Volumetric flow (litres/min)	1,716.87	1,716.87	898.23	
Volumetric flow (gallons)	453.00	453.00	237.00	
Throughput (tonnes/h)	4.13	4.13	2.16	
Throughput (US tons/day	108.70	108.70	56.90	
Net energy (kWh/tonne)	41.58	41.58	83.16	
Net energy (HPD/T)	2.10	2.10	4.20	
Gross energy (kWh/tonne)	63.60	63.60	125.21	
Gross energy (HPD/T)	3.22	3.22	6.34	

7. CONTACT LIST

There may be other suppliers of energy efficient refining equipment. Please consult your supply directories or contact the Environment and Energy Helpline on 0800 585794 who may be able to provide you with more details on request.

7.1 Refiner Manufacturers

Sandusky Walmsley
Crompton Way
Bolton
Lancashire BL1 8UL
England

Black Clawson International
East Dock Road
Newport
Gwent N9P 2TT
South Wales

Sulzer-Escher Wyss GmbH
Escher Wyss Paper Technology Div
PO Box 1380
Ravensburg W-7980
Germany

Voith Engineering
Ambassador House
Brigstock Road
Thornton Heath
Surrey CR4 7JG
England

Sunds Defibrator
10, Western Rd.,
Borough Green,
Kent TN15 8AG
England

Lamort Paper Services
40 Murdock Road
Bicester
Oxfordshire OX6 7PP
England

Andritz Sprout-Bauer Inc
Sherman Street
Muncy
PA 17756
USA

Pilao Intl Ltd
Unit 13
Dunscar Industrial Estate
Blackburn Road
Egerton
Bolton
Lancashire BL7 9PQ
England

Bematec
18 Grand-Pont
1002 Lausanne
SWITZERLAND
P.O. Box 2333

7.2 Control System Manufacturers

BTG UK Ltd
26 Breakfield
Coulsdon
Surrey CR5 2XW
England

Kajaani-Electronics
Carisbrooke Services
2 Tongham Road
Runfold
Farnham
Surrey
England

APPENDIX 1

USEFUL REFINING REVIEWS

Beating of chemical pulps - the action and the effects, D. H. Page. Presented at the Fundamental Research Symposium, 17-22 September 1989, Cambridge.

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Fundamental aspects of the refining process, S. Heitanen, K. Ebeling, Pap. Puu, Volume 72, No. 2, 1990, pp158-170.

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Some differences in the beating behaviour of softwood and hardwood pulps, J.E. Levlin, International Symposium on Fundamental Concepts of Refining, 16-18 September, Appleton, IPC, pp51-60.

Critical review of refiner theory, Third International Refining Conference, Atlanta, Georgia, 20-22 March 1995, Volume 2, Paper 13.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related topics please contact:
Enquiries Bureau
BRECSU
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For industrial and transport topics please contact:
Energy Efficiency Enquiries Bureau
ETSU
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OX11 0RA
Fax 01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.